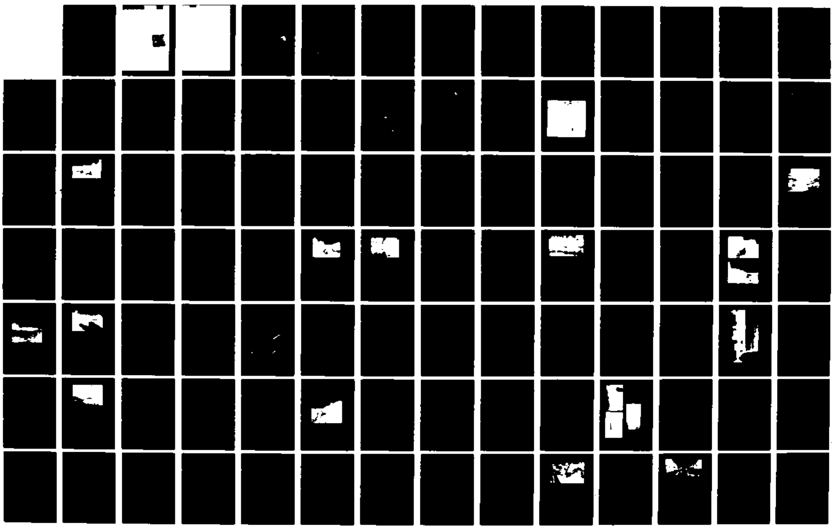
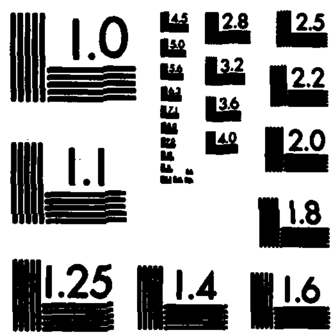
AD-A120 544 ENVIRONMENTAL FEATURES FOR FLOOD-CONTROL CHANNELS(U) 1/2
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS
ENVIRONMENTAL LAB F D SHIELDS JUL 82 WES/TR/E-82-7

UNCLASSIFIED F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report E-82-7	2. GOVT ACCESSION NO. AD-A120544	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ENVIRONMENTAL FEATURES FOR FLOOD-CONTROL CHANNELS		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) F. Douglas Shields, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS EWQOS Task VIB
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE July 1982
		13. NUMBER OF PAGES 133
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Channels (Hydraulic engineering)
Environmental impact analysis
Flood control

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents and documents preliminary findings of an information review performed to develop environmental guidance for flood-control projects that involve modification of natural stream channels by clearing and snagging, alignment, enlargement, and lining. The response of the fluvial system to modification sometimes results in unintentional or unforeseen environmental impacts.

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

In general, channel modification results in a shorter, smoother, more uniform channel with larger cross-sectional area and less natural vegetation. Overbank flooding is eliminated or reduced, and depths and velocities are changed at all flows. Since extreme channel instability has adverse effects on ecological and aesthetic resources, channel straightening should be minimized. The channel cross section should be designed for low as well as high flows; the existing velocity-versus-discharge relationship should be preserved as much as possible at low and intermediate flows to maintain the sediment transport characteristics of the existing channel. Environmental features have been found to have limited effectiveness unless the modified channel is reasonably stable, the project area is protected against further modification, and construction and maintenance work is closely supervised and inspected.

The adverse environmental impacts of channel enlargement can be reduced by following the existing channel alignment and excavating from one side only. Floodways may be used to preserve portions of the existing channel and its associated aquatic habitat. Low-flow channels may be constructed inside a larger channel, or the existing channel may be preserved as a low-flow channel. Pools and riffles may be constructed. Water control structures may be placed in the channel to maintain water levels for aquatic habitat and aesthetics and to prevent invasion and blockage. Meander loops may be maintained as small ponds or wetlands.

Many of the adverse impacts of channel work can be avoided by preservation of existing valuable vegetation and by prompt revegetation with appropriate species. Aquatic habitat diversity may be restored to a modified channel by placing simple habitat structures in the channel to create vertical relief, nonuniform flow patterns, and stable substrate; these devices should be used with care since they increase hydraulic roughness and tend to offset flood control measures. Biological recovery of some modified streams may be improved by armoring the new channel with biologically desirable coarse bed material. Adverse impacts of channel lining or paving may be addressed by incorporating natural materials such as boulders in the lining, by ponding water in the lined channel, and by constructing low-flow channels, fishways, pools, and spawning channels.

Modification of stream channels in urban areas frequently offers many opportunities for recreational development and beautification.

SUMMARY

The Federal Government and the Corps of Engineers have made a commitment to preserving and enhancing environmental quality. Specific guidance is needed to implement general environmental policy in the design, construction, operation, and maintenance of flood-control channels. The purpose of this report is to present and document the preliminary findings of an information review performed to develop environmental guidance for flood-control projects that involve modification of natural stream channels by clearing and snagging, alignment, enlargement, and lining.

A basic knowledge of the physical and ecological characteristics of natural streams is necessary to incorporate environmental considerations into a flood-control channel project. Natural alluvial streams are dynamic systems, and the physical variables of each system are highly interrelated. The response of the fluvial system to modification sometimes results in unintentional or unforeseen environmental impacts. Natural streams are usually physically diverse, with a variety of depths, current velocities, substrates (bed materials), and illumination patterns. This physical diversity gives rise to visual diversity that makes the stream an aesthetic resource. The physical diversity also provides the variety of habitats required to support a wide diversity of aquatic and terrestrial species. The natural stream is physically, chemically, and biologically related to its riparian areas and floodplain.

The adverse environmental impacts of flood-control channel modifications vary considerably from site to site, but they are frequently quite severe. Adverse impacts are directly or indirectly related to the physical modifications made to the channel and floodplain. In general, channel modification initially results in a shorter, smoother, more uniform channel with a larger cross-sectional area and less natural vegetation. Overbank flooding is eliminated or reduced, and depths and velocities are changed at all flows. Information on the ecological, aesthetic, and cultural resources of the project area should be studied and

considered in preliminary channel modification design in order to reduce or avoid adverse impacts.

Channel stability is important from both an engineering and an environmental viewpoint since extreme channel instability has adverse effects on ecological and aesthetic resources. From a stability standpoint, the existing channel alignment is generally best, and channel straightening should be minimized. The channel cross section should be designed for low flows as well as high flows. The existing velocity-versus-discharge relationship should be preserved as much as possible at low and intermediate flows to maintain the sediment transport characteristics of the existing channel.

In the absence of systematic research, several channel designers have experimented with various methods for reducing environmental impacts. Additional methods have been proposed by conservation and environmental protection agencies. In general, environmental features have been found to have limited effectiveness unless the modified channel is reasonably stable, the project area is protected against further modification, and construction and maintenance work is closely supervised and inspected. The individualistic nature of channel projects makes generalization about environmental features difficult.

Selective clearing and snagging is the process of removing only the trees and obstructions that significantly impede flow. Construction equipment and methods are controlled to preserve other vegetation and natural features.

The adverse environmental impacts of channel enlargement can be reduced by following the existing channel alignment and excavating from one side only. Floodways may be used to preserve portions of the existing channel with its associated aquatic habitat. Low-flow channels may be constructed inside a larger channel, or the existing channel may be preserved as a low-flow channel. Pools and riffles or shallows and deeps may be constructed in low-flow channels or in enlarged flood-control channels by varying the cross-sectional shape. However, constructed pools and riffles tend to be quite unstable. Some adverse effects of enlarging a low-gradient channel may be reduced by placing water control structures in the channel to maintain water levels for aquatic habitat, to preserve aesthetics, and to prevent invasion and blockage of the channel by invader species. Meander loops severed from the channel by relocation or realignment may be maintained as small ponds or wetlands by constructing channel blocks at either end.

Many of the adverse impacts of channel work can be avoided by preservation of existing valuable vegetation and by prompt revegetation of denuded areas with appropriate species. However, vegetated areas must be protected from grazing, clearing, or cultivation after project completion. Species for revegetation should be carefully selected to meet criteria of aesthetics, habitat value, hardiness, adaptation to site conditions, growth rates, and self propagation.

Aquatic habitat diversity may be restored to a modified channel by placing simple structures in the channel to create vertical relief, nonuniform flow patterns, and stable substrate. These devices increase hydraulic roughness and tend to offset flood-control measures; therefore planning for habitat structures requires sensible trade-offs. Habitat structures may be categorized as sills, deflectors, or random rocks. They have met greatest success in coldwater trout streams with beds of large gravel, cobbles, and boulders; however, some successful experiences have been documented on warmwater streams with finer bed material. Habitat structures are not feasible for extremely unstable channels or where water quality or quantity is insufficient for a viable fishery.

Biological recovery of some modified streams may be improved by armoring the new channel with biologically desirable coarse bed material. To be effective the "artificial substrate" must be fairly stable and must not be covered over by fine sediments.

Adverse environmental impacts of channel lining or paving may be addressed by incorporating natural materials such as boulders in the lining, by ponding water in the lined channel, and by constructing low-flow channels, fishways, pools, and spawning channels.

Modification of stream channels in urban areas frequently offers many opportunities for recreational development and beautification; higher population densities in urban areas make these environmental considerations more practical. Channels and floodways especially lend themselves to development of trails alongside. Channel projects in high visibility areas may be made aesthetically pleasing by special plantings and by the use of specially colored and textured construction materials. Recreation and beautification features will require additional maintenance after high flows. Vandalism may also necessitate additional maintenance and surveillance.

PREFACE

This report was prepared as the part of the Environmental and Water Quality Operational Studies (EWQOS) Program, Task VIB, Design and Construction Techniques for Waterway Projects. The EWQOS program is sponsored by the Office, Chief of Engineers, and is assigned to the U. S. Army Engineer Waterways Experiment Station (WES), under the purview of the Environmental Laboratory (EL). Dr. J. L. Mahloch, EL, is Program Manager of EWQOS.

The study was conducted during the period April 1981 to September 1981 by Mr. F. Douglas Shields of the Water Resources Engineering Group (WREG), Environmental Engineering Division (EED), EL. Mr. Shields worked under the direct supervision of Mr. Michael R. Palermo, Chief, WREG, and under the general supervision of Mr. A. J. Green, Chief, EED, and Dr. John Harrison, Chief, EL.

The Commander and Director of WES during this study was COL Tilford C. Creel, CE. The Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Shields, F. D., Jr. 1982. "Environmental Features for Flood-Control Channels," Technical Report E-82-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, INCH-POUND TO METRIC (SI) UNITS OF MEASUREMENT

Inch-pound units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4.046873	square kilometres
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pounds	0.4535924	kilograms
pounds (mass) per square inch (psi)	6.894757	kilopascals
square feet	0.09290304	square metres
tons (short, 2000 lb)	907.8147	kilograms

ENVIRONMENTAL FEATURES FOR FLOOD-CONTROL CHANNELS

PART I: INTRODUCTION

Background

1. The Corps of Engineers (CE) is committed to implementing the National Environmental Policy Act (NEPA), other environmental statutes, and environmental guidelines issued by the Executive Branch. Several CE documents have translated Federal environmental statutes and policies into Corps policies. For example, Engineer Pamphlet (EP) 1165-2-501 (Department of the Army, Office, Chief of Engineers (OCE) 1976) contains the general guideline that specific environmental considerations be integrated into the planning and design of all project features to ensure that qualitative values associated with the project are enhanced, preserved, or maintained. EP 1165-2-501 also offers general guidance for consideration of fish and wildlife habitats, aesthetic resources, cultural resources, and historical and archaeological features in project planning and design. Additional general guidance is found in Engineer Regulation (ER) 1165-2-2 (OCE 1967) and Engineer Manual (EM) 1110-2-38 (OCE 1971). Keeley et al. (1978) present a summary of legislative acts and Executive Orders that relate to environmental aspects of the CE Civil Works program.

2. Although general policies regarding consideration of environmental quality have been formulated, more specific guidance is needed to implement these policies in project planning, design, construction, operation, and maintenance. The CE is currently conducting a large-scale, multiyear research program, the Environmental and Water Quality Operational Studies (EWQOS), to address high-priority environmental problems. The objective of Work Unit VI.B of the EWQOS Program is to facilitate implementation of Federal and CE environmental policies by providing new or improved design and construction guidance for waterway projects to

meet environmental quality objectives. This report contains the interim findings of Work Unit VI.B relevant to flood control channel projects.

Purpose

3. The purpose of this report is to document the preliminary findings of an effort to develop environmental guidelines for flood-control channel projects. The contents of this report do not constitute CE policy or design guidance and therefore should not be regarded as such. Contents of this document, ongoing research, and field experience will provide input for an environmental EM on flood-control channels.

Scope

4. This report deals with environmental matters pertaining to flood-control channels not open to commercial navigation. Primary emphasis is on projects that involve clearing and snagging, enlargement, alignment, grade control, or relocation of natural stream channels. General environmental considerations for preliminary design are presented, and several types of environmental features are described. Environmental considerations for channel construction and maintenance are also covered.

5. Information contained in this report was obtained from literature review, interviews, and case studies of completed channel projects that have incorporated specific measures to reduce environmental impacts. Such projects were identified by submitting questinnaires to appropriate State and Federal agencies. Case studies included site inspections; interviews with project designers; and review of relevant documents such as environmental impact statements, design memoranda, and research reports. This report has been written for a general audience, as well as for CE engineers and life scientists.

PART II: ENVIRONMENTAL CONSEQUENCES OF CHANNEL MODIFICATION

Introduction

6. The environmental impacts of channel modifications for flood control have been discussed by a number of authors. However, since impacts vary considerably both in type and magnitude from one site to another, impacts reported for previous projects are useful primarily as a general guide. The purpose of this chapter is to aid the channel designer in identifying the significant physical and biological characteristics of a particular stream so that he may preserve and enhance these characteristics in a manner consonant with project constraints and objectives. This chapter is not intended to be an exhaustive treatment of stream sciences and the environmental impacts of channel modification; instead, it is a general introduction. For more detail the reader should communicate with associates in other disciplines and authorities on the specific geographical and functional areas under consideration.

References

7. Thorough discussions of the physical characteristics of natural streams are given by Shen (1971), Schumm (1977), Gregory and Walling (1973), and Morisawa (1968). Briefer, more general treatments are given by Nunnally and Keller (1979), Darnell et al. (1976), and White and Byrnildson (1967).

8. Biological characteristics of streams are described by Hynes (1970) and Whitton (1975). Briefer treatments are given by Darnell et al. (1976), Funk (1973), and White (1973).

Characteristics of Unaltered Streams

9. Natural streams transport both water and sediment from within their drainage basins to receiving water bodies. The variables of the fluvial system; i.e., channel width, depth, and longitudinal profile;

channel roughness; discharge; sediment load; sediment characteristics; channel alignment; velocity distribution; etc., are interrelated in a complex fashion that is only partially understood at present. The response of fluvial systems to changes in these variables indicates that relationships between the variables exist, although the exact relations may vary with both space and time (Chorley and Kennedy 1971). The complexity of fluvial systems makes it difficult to express mathematically the relationships between even statistical means of system variables. Water discharge and sediment load integrate most of the other variables, and empirical relationships between morphologic variables (width, depth, sinuosity, slope, etc.) and water discharge or sediment load have been derived that are valid for a given stream or stream reach. Schumm (1971) presents a qualitative classification system for alluvial channels based on sediment characteristics and channel stability. Classification systems are useful, but should be used with care since streams tend to be individualistic.

Channel form

10. Natural stream channels may be composed of materials that are transported by the stream, or they may be partially or completely controlled by outcrops of rock or erosion-resistant cohesive materials. Unaltered channels are usually sinuous, i.e. braided or meandering, except for short reaches. Straight channel reaches normally occur on extremely flat or extremely steep slopes. The meandering channel is the most common channel form. For many streams the average meander length is fairly uniform and may be expressed as a constant times the width (see Figure 1). If measured in a straight line, the meander length ranges from 7 to 10 times the channel width; along the channel, meander length varies from 11 to 16 times the width (Leopold, Wolman, and Miller 1964; Keller 1978). Braided channels are composed of numerous interconnected channels separated by bars which appear as islands at low flow. Braided streams are often found on fairly steep slopes and carrying high sediment loads. Although they are quite flat, deltas are also frequently braided. Many transitional forms between straight, braided, and meandering have been observed.

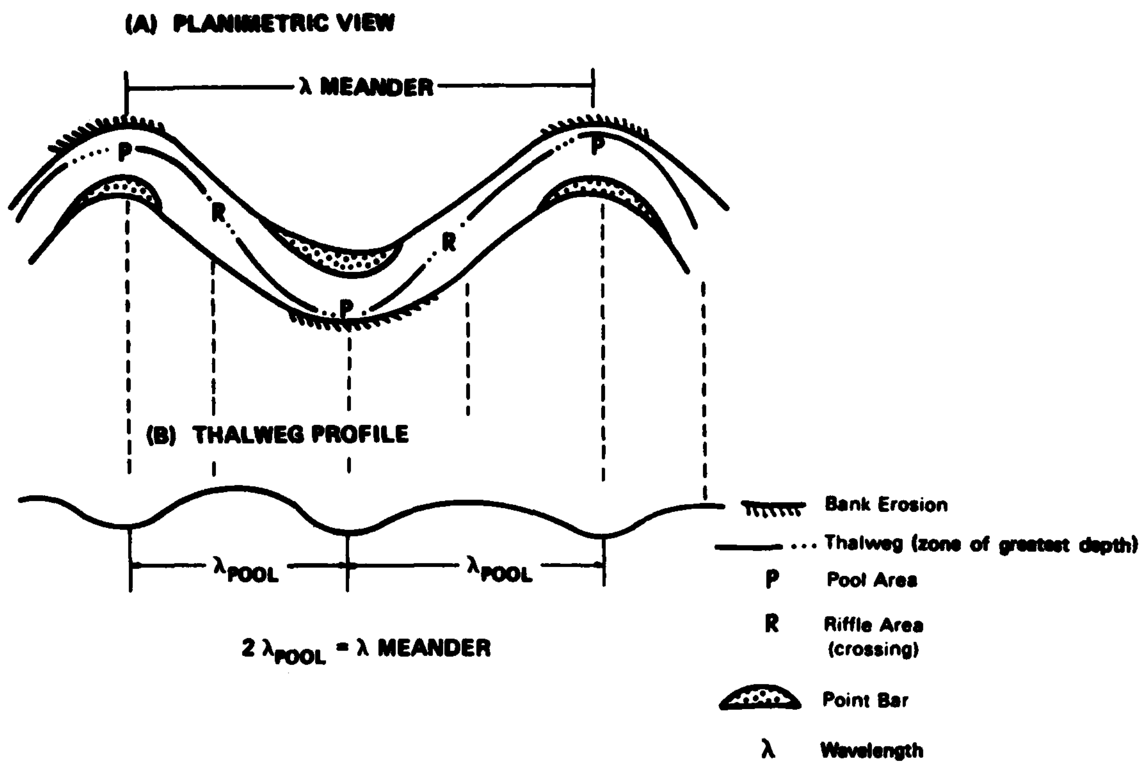


Figure 1. Pools and riffles in sinuous streams: most pools are located opposite point bars, and riffles are found between the pools at the thalweg crossover (Nunnally and Keller 1979)

Pool-riffle complex

11. In smaller streams, meandering alignment is associated with a predictable distribution of depths, velocities, and bed material. Swiftly flowing shallows (riffles) with coarser bed material are normally located in the "crossings" below the points of inflection of a meander loop (Figure 1). Slower moving deeps (pools) with finer substrate are located on the outside of bends, and point bars are generally found on convex banks opposite pools (Figure 1). The pool-riffle complex is a dynamic component of the unaltered fluvial system and will adjust to a wide range of flow conditions, maintaining a roughly constant frequency and spacing of pools and riffles. Current theory about the stability of natural pool-riffle sequences is summarized by Karr, Toth, and Garman (1981). Even larger streams with finer bed material and relatively straight streams normally have a system of alternating point

bars that give rise to a series of deeps and shallows similar to the pool-riffle complex (Leopold, Wolman, and Miller 1964). Erosion of the outsides of bends and deposition on inside point bars cause meanders to gradually migrate downstream and increase in amplitude. When the meander loop becomes greatly extended, a natural cutoff across the point bar on the convex bank sometimes occurs and the channel changes its course. For a period of time the flow may be divided between the old meander channel and the new cutoff, but gradually the shorter channel captures more and more of the flow. Midchannel bar deposits, split channels, islands, back chutes, secondary channels, and oxbow lakes are also characteristic of natural alluvial channels.

<u>Habitat diversity</u>

12. Meandering channels and their pool-riffle complexes are diverse habitats that contain standing and flowing water with a wide variety of substrates such as mud, sand, gravel, stone, and vegetation (Figures 2 through 5). This range of physical conditions supports a diverse aquatic community. For example, most benthic invertebrates are adapted to particular current conditions and substrate materials, and the variety of habitats found in many unaltered streams supports adverse assemblage of benthic organisms. Gravel riffles are utilized for spawning by many species of fish that deposit eggs in gravel. The shallow, turbulent flow in riffles maintains the high oxygen concentrations required for incubation. Pools, on the other hand, provide habitat for fish food organisms, cover for adult fish, and nursery areas for larval and juvenile fish. Additional habitat diversity

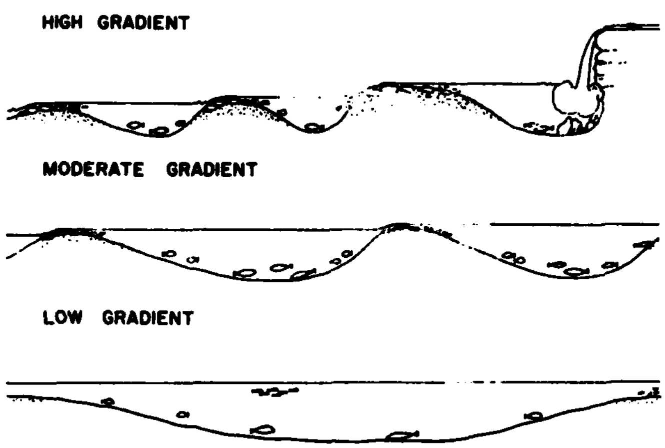


Figure 2. Linear diversity in a stream and its relation to gradient (stippling indicates coarser bed material) (Funk 1973)

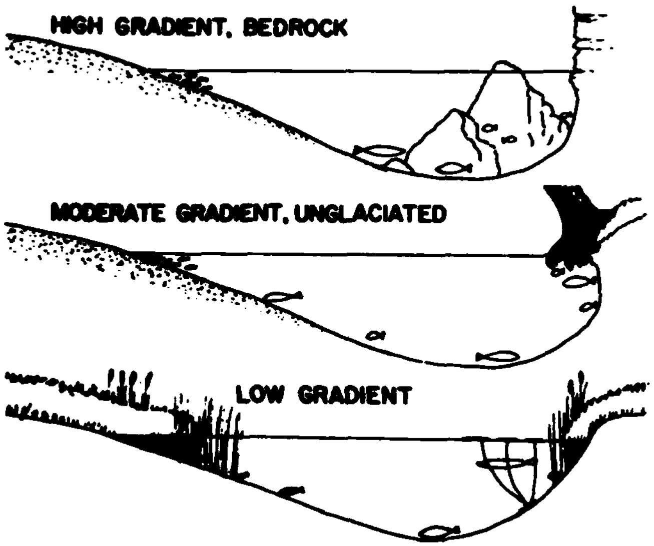


Figure 3. Cross-section diversity of pools in various geologic situations (Funk 1973)

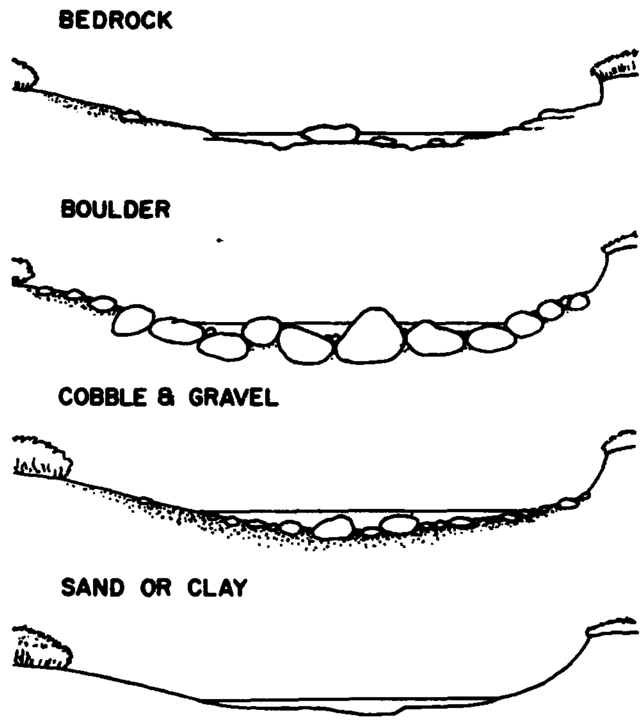


Figure 4. Cross-section diversity of various types of riffles (Funk 1973)

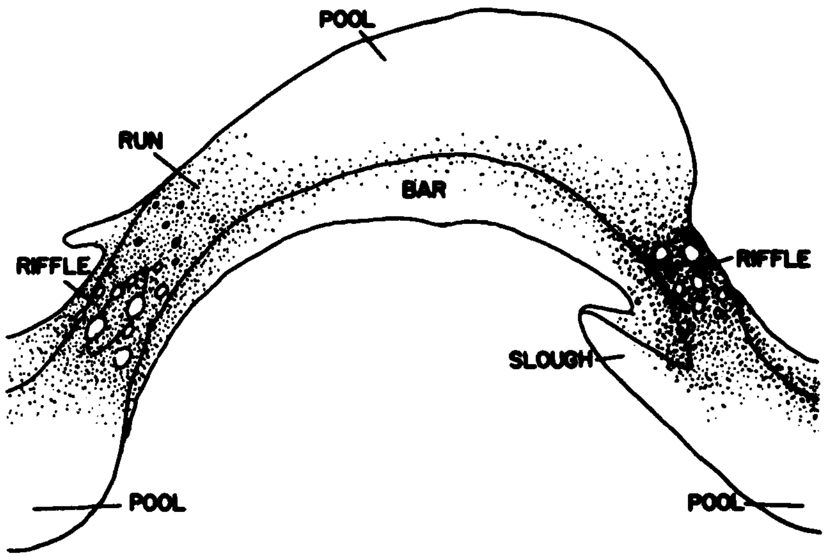


Figure 5. A meander in a stream and how it contributes to diversity (stippling indicates coarser bed material) (Funk 1973)

is provided by off-channel sloughs, chutes, and oxbow lakes. Although these backwater areas may be hydraulically connected with the stream only during high water, they can serve as spawning and nursery areas for stream-dwelling organisms. They also furnish habitat to reptiles, amphibians, birds, and mammals (Darnell et al. 1976; Gorman and Karr 1978).

Riparian vegetation

13. The area of wetland and terrestrial vegetation adjacent to and hydrologically affected by a stream is highly significant. Documented values include economic, scientific, aesthetic, educational, recreational, and ecological (Brinson et al. 1981). The importance of this vegetation to wildlife is especially striking (Johnson and Jones 1977). For example, in the Southwest, 50 percent of the nesting bird species are totally dependent on water-related habitat, and an additional 27 percent are partially so dependent (Johnson, Haight, and Simpson 1977). Vegetated riparian zones provide a corridor of scarce, high-quality habitat through many agricultural and urban areas.

14. Riparian vegetation is also quite important to the aquatic community, especially for smaller streams that are completely or almost

completely canopied by vegetation. The canopy of shade reduces solar radiation reaching the channel, thereby reducing maximum water temperature and controlling photosynthesis which are major factors in determining aquatic community structure. Riparian vegetation sheds leaves and twigs into the stream that are the primary food source for invertebrates at the base of the aquatic food chain, and in some streams this coarse particulate organic matter (CPOM) is the primary energy input into the stream ecosystem. Organisms in smaller streams process the CPOM and pass finer particles of organic matter downstream to be utilized by organisms adapted to smaller particles and downstream conditions (Cummins 1974). Fallen trees and undercut roots of streamside trees provide cover, shelter from current, and points of orientation for fish (Marzolf 1978). Riparian vegetation can also benefit aquatic habitat by influencing channel shape. Gammon and Mays (1981) examined several small Indiana streams and found pool depths were greater for reaches with buffer strips of riparian vegetation. Riparian vegetation can stabilize channel morphology by reinforcing banks and by reducing local current velocity next to the bank. Riparian vegetation affects water quality by reducing maximum temperatures, stabilizing banks (Allen 1979), and controlling photosynthesis in the channel, and by filtering local overland flow, thus reducing sediment and nutrient inputs to the stream (Karr and Schlosser 1977).

<u>Substrate</u>

15. The material composing the bed and banks of a stream serves as a substrate for benthic organisms which are food for higher organisms such as fish. In general, coarse, stable substrates with a wide gradation of particle and void sizes are much more productive than sandy, shifting beds. Large rocks also offer cover and shelter from current for vertebrates. Fine-grained organic muds can be quite productive habitat for invertebrates if the muds are sufficiently stable (Hynes 1970, Tarzwell 1932 and 1936).

<u>Aesthetics</u>

16. The aesthetic value of a particular landscape is subjective and may vary considerably from one individual to another. Natural

streams are frequently regarded as valuable aesthetic resources because they display an evident harmonious relationship of all parts (Figure 6). Visual resources associated with natural streams may include a zone of trees which can provide variety and spatial definition to the surrounding landscape; clear water; desirable drift material such as leaves; a variety of bottom materials, or bottom materials unique for the area; and a variety of conspicuous water movement, from fast reaches to still pools. Visual diversity is offered by riparian vegetation of varying sizes,

Figure 6. A natural, free-flowing stream

shades, and hues; a variety of streambank slopes; a sinuous channel alignment; and a variety of cross-sectional sizes and shapes. Plant species adjacent to streams are sometimes unique compared to the surrounding landscape. Areas such as lawns, gardens, or parks in the vicinity of urban streams can be valuable visual resources if they are well maintained (U. S. Department of Agriculture Soil Conservation Service (SCS) 1977). All natural streams are not generally considered to be aesthetic resources, however. The aesthetics of some urban streams have actually been improved by flood-control modifications.

Hydrologic interrelationships

17. The natural stream is related to the groundwater table and floodplain in a number of ways which facilitate physical, chemical, and biological interaction. Floodplain plant and animal communities have adapted to the duration, timing, and frequency of flooding. The groundwater table may be recharged by flood flows which inundate a broad expanse of floodplain, thus allowing water to percolate through the upper layers of soil. A portion of high flows is stored as groundwater and gradually released back into the stream; often groundwater is the only inflow for small streams during drought. In some climatic zones the surface flow will recharge the groundwater during low flows. A swamp or marsh created by a very low, flat floodplain acts as a reservoir for the associated stream, damping out extremes in flow. Wetlands are flushed by high flows, which sometimes prevents anaerobic conditions. Nutrients and sediment are removed from the floodwaters as they spread across floodplains or wetlands, relieving downstream areas from environmental stress caused by nonpoint source pollutants (Darnell et al. 1976).

Flood-Control Channel Modifications

18. The cross-section, slope, and planform of a natural channel, and thus its flow capacity, are determined by natural processes in accordance with the laws of physics. Although extensive data are not available, Henderson (1966) summarizes the results of two studies of natural channel capacity. Natural channels were found to have bankfull

capacities roughly equal to events with return intervals of six to nine months. A natural stream channel may be made more hydraulically efficient by modification, thus reducing the frequency of overbank flooding. Channel roughness is decreased by removing trees and snags from the channel bed and banks and by constructing a more uniform cross section with a straighter alignment. Channel capacity may be increased by excavating a larger cross section, and the driving force for the flow may be increased by increasing the channel slope. Where land costs are high, the channel may be lined or paved to withstand higher velocities, thus reducing the cross-sectional area required to pass the design flow. By reducing the frequency and/or duration of overbank flooding, channel modifications make it possible to cultivate or develop the floodplain with less risk. The results of channel modification may be short-lived if the new channel is extremely unstable or if vegetation quickly invades and blocks the new channel.

Adverse Impacts of Flood-Control Channel Modifications

Literature synthesis

19. Synthesis of the adverse environmental impacts of flood-control channel modifications described in existing literature reviews and broad-based reports (Arthur D. Little, Inc. 1973, Barton and Winger 1973, Darnell et al. 1976, Bulkley et al. 1976, Griswold et al. 1978, Parrish et al. 1978) provides a general overview of problem areas. The type and magnitude of impacts vary considerably from site to site. A cumulative list of adverse environmental impacts may be categorized as follows:

a. Aquatic habitat. Loss or change of aquatic habitat or habitat diversity leading to undesirable shifts in production, diversity, density, and composition of aquatic communities.

b. Terrestrial and wetland habitat. Loss or change of terrestrial and wetland habitat or habitat diversity leading to undesirable shifts in production, diversity, density, and composition of terrestrial and wetland communities.

c. Channel instability. This may produce increased sediment concentrations and turbidity, bank caving and sloughing, channel aggradation and degradation, and head cutting.

d. Aesthetics. Degradation of the aesthetic values of streams and riparian areas.

e. Water quality. Water quality degradation, principally increased temperature and sediment concentration.

f. Hydrology. Changes in hydrologic conditions including lower water tables, wetland drainage, greater variation of discharge, decreased overbank flooding, increased downstream flood stages, intermittent flows, and increased uniformity of flow depth and velocity.

Relationship to physical changes

20. Adverse environmental impacts of flood-control channel modifications are related to the intentional and unintentional physical changes in the channel and floodplain (Figure 7). In general, modification tends to produce a smoother, straighter channel with a larger cross-sectional area and less riparian woody vegetation. Longitudinal slope is frequently increased. In addition to reducing the frequency and duration of overbank flooding, flood control modifications also affect depths and velocities at all flows. Relationships with contiguous wetlands and shallow aquifers may be altered as well.

21. Aquatic habitat. Numerous case studies (Lund 1967, Arthur D. Little, Inc. 1973, Arner et al. 1976, and Headrick 1976) have shown that many, though not all, flood-control channel projects affect fish populations. Typically, the total number of fish is reduced, total weight is reduced, and the size distribution is skewed more toward smaller fish. These effects occur because channel modifications reduce both the total amount of aquatic habitat (stream length) and the habitat diversity needed to support a viable fishery and the lower life forms that provide food for fish. For example, compared to an unaltered stream a modified channel may be all pool or all riffle. Modified channel substrates are frequently finer than the original streambed and/or poorly sorted. Water quality degradation caused by channel modification can affect fish populations. Removal of riparian vegetation and snags reduces the cover and structure needed by fish for orientation and for refuge from strong currents and predators. Such removal also reduces the input to the

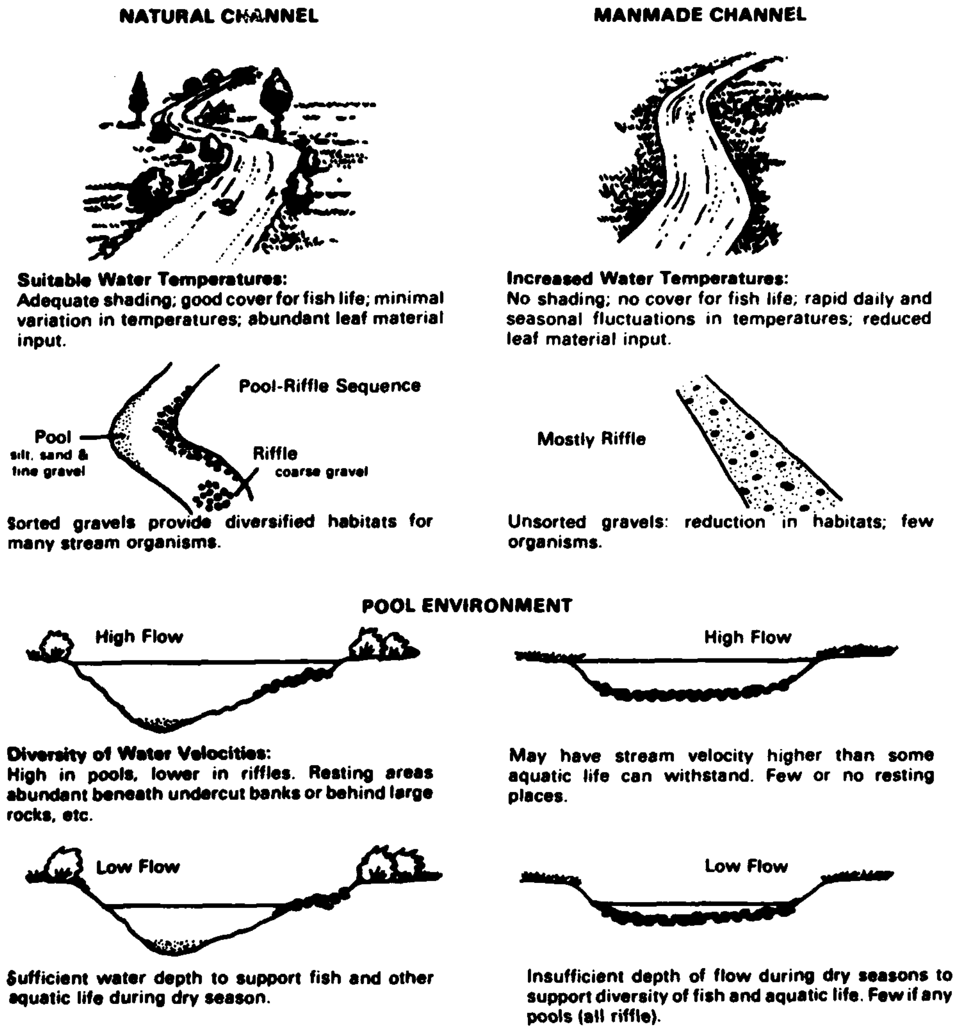


Figure 7. Typical physical changes and attendant environmental impacts due to channel modification (Nunnally and Keller 1979, after Corning 1975)

stream of organic matter (twigs and leaves), the primary energy source for many small stream ecosystems (Marzolf 1978).

22. Terrestrial and wetland habitat. Flood-control channel modifications impact wetland and terrestrial habitats both indirectly and directly. Indirect losses of habitat occur when such areas are converted to urban or agricultural use due to improved drainage or reduced flood risk. Direct impacts occur due to clearing of vegetation and other construction activities, such as staging, movement of equipment, construction

of haul roads, and disposal of excavated or dredged material. Further direct impacts of channel modification occur when improved drainage and less frequent overbank flooding lead to dryer conditions, particularly at low flows. These dryer conditions can shift plant community structure toward less flood-tolerant species and decrease overall productivity and wildlife habitat value (Barclay 1980). Off-channel aquatic areas may shrink or disappear as they drain into a lowered stream channel or dry up. The quality of terrestrial and wetland riparian habitats can be directly affected by channel modifications. Beaver and muskrat, for example, are affected by water depth, bank slope, and bank soil texture, since these factors determine the availability of den sites (Arner et al. 1976). Small mammals are affected more than large mammals, probably due to the fact that larger species have a larger home range and can find other water, food, and cover (Barclay 1980, Dodge et al. 1976).

23. Channel instability. Changes in channel geometry, roughness, longitudinal slope, or increased or decreased inputs of water or sediment can lead to channel instability* (Figure 8). Channel instability may also result when riparian vegetation is removed. Channel modifications are usually designed to prevent serious instability problems, but such problems sometimes occur anyway because it is difficult to predict responses of fluvial systems to modification. In addition to structural problems, such as bank failure and destruction of bridges and other channel crossings, channel instability also has an adverse affect on water quality, aesthetics, and aquatic habitat. Water quality is degraded by increased concentrations of sediment and associated constituents. Caving banks, turbid water, and excessive deposition of sediment degrade the aesthetic quality of a stream. Prolonged increased levels of sediment are detrimental to the aquatic community. In most regions, unstable, fine, shifting substrates are vastly inferior to coarse, stable materials for benthic invertebrate habitat and fish cover (Hynes 1970). However, stable deposits of fine-grained cohesive material can form

* Channel instability as used here refers to unusually rapid bank erosion, lateral migration, degradation, aggradation, and the like.

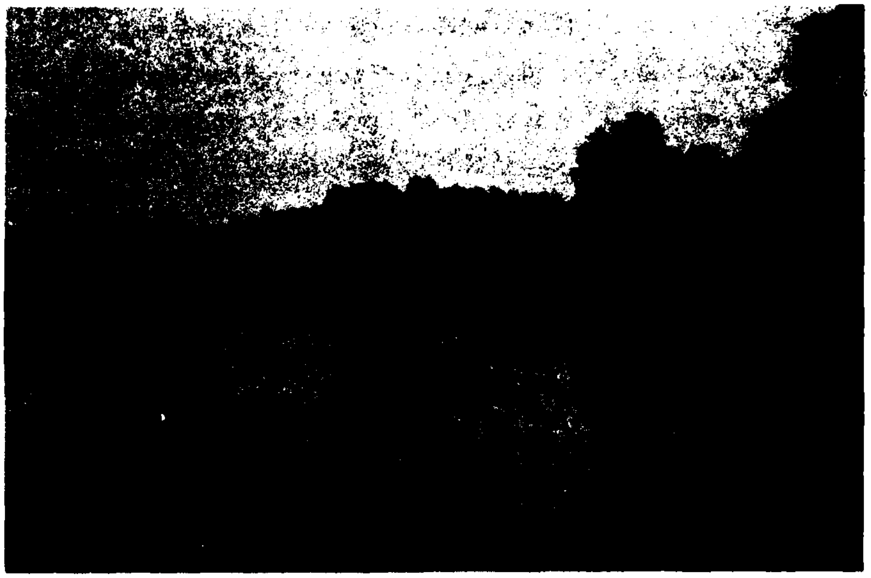


Figure 8. Channel instability. Twenty-Mile Creek, Mississippi

productive substrate in some streams.

24. Aesthetics. Poorly designed channel modification projects can seriously degrade valuable aesthetic resources. Modified channels frequently create a monotonous landscape characterized by straight lines, homogeneous flow patterns, turbid water, and weedy vegetation (SCS 1977). Flood-control channel projects frequently have an artificial appearance that is in conflict with the surrounding landscape. Unique features or scenic vistas may be obscured or removed, and belts of trees that act as visual screens or windbreaks are sometimes removed. Eroding mounds of material excavated from the channel, straight channel alignments, extensive streambank erosion, uniform flow conditions, and weedy vegetation (predominantly invader species) are visually displeasing to most observers (Dale 1975). On the other hand, a flood-control channel with clean lines, graceful bridges, and an overall neat appearance may be harmonious with some urban settings and more pleasing than the severely degraded stream which preceded it. Aesthetic values are perceived differently by different observers.

25. Water quality. The most common impacts of channel modification on water quality are increased sediment concentrations and

increased temperatures, although changes in both physical and chemical water quality characteristics may be caused by increased or decreased groundwater contributions at low flow. Increased temperatures result from reduced shade, shallower flows, heating and reflection from channel lining and bank protection, and higher turbidity levels that increase the amount of solar radiation absorbed by the water. Increased temperatures in turn affect temperature-dependent parameters such as dissolved gases. Increased sediment concentrations are caused by channel instability, streambank erosion, and higher water velocities, or by land-use changes in the watershed. Constituents such as contaminants and nutrients associated with the sediment increase as well. In some cases changes in hydraulic characteristics or in the shape of the hydrograph can affect removal rates for various types of pollutants (Wharton and Brinson 1978). Channel modifications which drain or destroy riparian wetlands have been observed to increase nutrient concentrations and reduce organic carbon concentrations in associated streams (Kuenzler et al. 1977, Montalbano et al. 1979). The type and significance of water quality impacts associated with channel work vary considerably from site to site. Water quality impacts may gradually disappear as the modified channel stabilizes and riparian vegetation recovers. (Winner and Simmons 1977, Kuenzler et al. 1977, Parrish et al. 1978, Dale 1975, Huish and Pardue 1978, Karr and Schlosser 1977). Few definitive studies on the water quality impacts of channel modification have been published, and site-specific factors are usually significant.

26. Hydrologic impacts. Increasing the flow capacity of a channel reduces the frequency and duration of overbank flooding. Surface recharge of shallow aquifers by flood flows is reduced, as are exchanges of water between the stream and adjacent wetlands. If the average water surface elevation of the stream is lowered, adjacent wetlands may be drained and/or groundwater tables lowered. Reducing floodplain storage through the modified reach may affect the shape of upstream and downstream hydrographs. For example, downstream peak discharges may be increased by a more efficient modified reach upstream.

PART III: ENVIRONMENTAL CONSIDERATIONS FOR PRELIMINARY DESIGN

Introduction

27. All individuals involved in planning, design, construction, operation, and maintenance of flood-control channel modification projects should understand the importance of treating the stream, the drainage basin, and associated resources as a unified system. To minimize adverse impacts of channel modification, environmental objectives must be clearly defined prior to detailed design; designers should gain understanding of these objectives by reviewing information gathered in earlier stages of the project, as described below. Unconventional environmental features may be disregarded or mishandled by contractors in the absence of close inspection and financial penalties for poor performance. Certain environmental features may require special types of post-construction monitoring and adjustment maintenance.

Geomorphology*

28. In the interest of producing a modified channel that is stable, aesthetically pleasing, and has minimal impacts on terrestrial and aquatic habitat, a study should be made of the geomorphologies of the existing channel and similar, nearby streams. In some cases information needed for this study will already have been collected for other purposes. One approach to such an effort is a three-phase study. In Phase One to the extent possible, the condition and morphology (i.e. longitudinal profiles, cross sections, plan) of the channel prior to any modification and the timing and nature of all previous channel

---

* Most of the material in this section comes from notes of a lecture presented by A. S. Harrison, U. S. Army Corps of Engineers, Missouri River Division, as part of a training course on Hydraulic Design of Flood-Control Channels, 23-27 February 1981, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

modifications are determined. In Phase Two existing conditions, including morphology, bed and bank materials, sediment movement, bank vegetation, adjacent land use, hydrology, and hydraulic parameters are studied. The erodibility of the various deposits in the area of proposed modification should be documented, and depositional zones (point bars, backswamps, sloughs, etc.) should be located and classified. In Phase Three the aforementioned data and estimates of the fluvial response to proposed modifications are analyzed. Shen et al. (1981) contains some good examples of this type of approach applied to the analysis of existing highway river crossings. Sources of information for geomorphologic study include maps, aerial photographs, old surveys, archives, old construction plans, interviews of residents, and site inspections. Geologic borings made for other work in the area sometimes yield useful information. SCS (1977) contains additional suggestions for geomorphologic investigations for channel work.

Map study

29. Maps and aerial photographs are valuable sources of information about a stream. Long reaches of the channel both upstream and downstream of the project should be studied, as well as the reach to be modified. The alignment of the channel in the valley and the frequency and uniformity of meanders should be noted. Old maps can be studied to yield information on the rate of lateral migration. Longitudinal profiles of both the valley and the channel should be plotted, and anomalies and discontinuities such as ledges, hard points and other local geological controls should be identified. Changes in the profile over time should be studied and their probable causes determined. Elevations for plotting profiles may be extracted from topographic survey maps.

Site inspection

30. Inspection of the existing channel can yield additional valuable information. The entire length of the channel should be examined on the ground. Longitudinal profiles may be surveyed along the thalweg (line of greatest depth). Survey points should be chosen at points of inflection, or at a break in slope, and not merely at equal

horizontal intervals. Particular attention should be given to channel dimensions (i.e. depth, width, bank slopes) and shapes. Cross-sectional shapes are usually an indication of the resistance of bank materials to erosion. Instances of bank caving, slumping, and channel downcutting should be noted. The type and condition of streambank vegetation and vegetation on bars should be noted, as these are indications of channel and bank stability and factors in channel roughness. The relationship of channel invert elevation to the surrounding topography should be noted. For example, the channel may be perched between natural levees or incised. Pfankuch (1978) presents a simple, yet quantitative stability rating system that can be useful in recording some visual observations.

31. Bed and banks. Materials composing the channel bed and banks should be examined as part of the site inspection effort. A survey of materials underlying the channel bed and banks should also be performed prior to layout of the modified channel grade and alignment. Special provisions will have to be made for exposed deposits of highly erodible material such as sand. The bed material can be loosely grouped into the following categories:

a. "Alluvial." A deep bed of material (usually sand and gravel) the stream is currently transporting, scouring, and depositing.

b. "Nonalluvial." Cohesive silts and clays may scour, but they become suspended load and do not redeposit in large amounts. Consequently, the nonalluvial channel bed will have a thin layer of transported sediment with more resistant material underneath (i.e., sand on cohesive clay or silt, sand on stone, or sand among cobbles or boulders) that does not move during normal flows.

c. Rock-controlled. Rock, shale, or very stiff clays.

Such categorization is general, but helps in organizing information. A more elaborate system of classification is found in Schumm (1981).

32. Channel instability. Any existing stability problems should be carefully studied and documented. Tributaries should be explored for unraveling and headcutting. Bridge crossings should be examined for trends of widening and degradation. The mode of instability should be

identified. Examples include headcutting due to a downstream disturbance, excessive inputs of sediment from the watershed, or increasing discharge.

Hydraulic roughness study

33. Note the role vegetation or shifting sand bars play in determining the hydraulic roughness of the existing channel. Hydraulic roughness (Manning's n)* may be a function of discharge in wide, sandy channels. The hydraulic roughness of the existing stream may be determined by reproducing flood profiles with backwater computations. Other reaches of the same stream with different physical characteristics can be analyzed in a similar fashion to determine the effect of these physical parameters on hydraulic roughness. Analysis of an existing modified reach of the stream in question or a similar stream can be quite helpful.

Ecological Resources

34. Flood-control channel projects should be planned and designed with full consideration of the existing ecological resources of the project area. Close intra- and interagency coordination among biologists and specialists in other disciplines such as hydraulics, geology, and soils is necessary to achieve a desirable project.

35. An inventory of the ecological resources of the area normally precedes detailed design. The purpose of the inventory is to describe the major ecosystems that make up the study area. The ecosystems are considered in terms of their functional characteristics, e.g. production or nutrient cycling, and their structural characteristics, e.g. existing species populations and communities. A major emphasis in the inventory of resources is consideration of the habitats making up the study area. Both distribution and quality of habitat are considered for each habitat type occurring in the study area. The quality of the habitat is

---

* Manning's n is a measure of hydraulic roughness. Chow (1959) gives typical values of Manning's n for various channels. Modifications for flood control are generally designed to decrease hydraulic roughness.

evaluated by considering the extent or area covered by each habitat type and the ability of the habitat to provide habitat requirements for feeding, cover, reproduction, and special needs. The presence of threatened or endangered species, as well as their habitats, will be noted.

36. After preliminary planning and design, additional studies will report on the projected impacts of the project on the existing ecological resources. These studies should differentiate between short-term and long-term impacts. A realistic analysis of the impacts associated with project maintenance should also be included.

37. Frequently channel designs can be modified to reduce ecological impacts by tailoring hydraulic and structural design to the project site, thus preserving valuable habitat or developing similar new habitats to replace areas unavoidably destroyed. More information about environmental features for flood-control channels can be found in Part IV of this report.

Aesthetic Resources

38. Flood-control channel planning and design should include consideration of the appearance of the completed project. The importance of a particular aesthetic or visual resource is partially determined by the use it receives, its visual resource value, and its visibility. The term "visual resource" is defined as the appearance of the landscape as described by measurable visual elements, such as topography, vegetation, water, and motion, and measurable patterns of interaction among these elements. Aesthetic resource uses include pedestrian paths or parks adjacent to streams. Visual resource value is the relative desirability of a visual resource determined by rational criteria. Visibility has to do with the numbers of people who see the project, how frequently and how long they see it, and what parts of the project are within their view. The viewer's frame of reference--whether he is a tourist, local resident, at work, or recreating--is also important (SCS 1977).

39. The impact that a flood-control channel has on visual

resources is determined primarily by the dominance of the channel and the contrast caused by the development of the channel. The dominance of a channel is determined by the channel's size and prominence when viewed in the context of the existing landscape. The contrast caused by the channel is the extent to which the channel differs from the surrounding landscape in terms of the visual elements of line, form, color, and texture (Smardon 1979).

40. Aesthetic considerations for flood-control channels are especially important for highly visible channel reaches. The final appearance of some reaches of urban channels, channels adjacent to transportation arteries, and bridge crossings all warrant additional attention, even though it is usually more difficult to develop or maintain aesthetic resources in these settings.

41. Landscape architecture is a growing discipline that deals with the analysis, planning, design, and management of visual resources. The landscape architect should therefore be a part of the flood-control channel planning and design team. Stone (1979) gives a good introduction to visual resource management and associated literature.

Cultural and Recreational Resources

42. Preliminary planning and design should also involve consideration of the past, present, and future human uses of the stream and adjacent areas. Sites of unusual historical or prehistorical significance should be identified to allow for possible avoidance or preservation. Avoidance is usually more economical than, and preferred to, preservation. Cultural investigations should be completed prior to final location of channel right-of-way and disposal areas. Existing and projected recreational use of the project area should be estimated.

43. Factors important to the value of a recreational resource include proximity, access, and ownership. An indication of the proximity factor is the population within an hour's drive of the project. Usage of the recreational resource can be strongly influenced by the availability of all-weather public roads for access. Normally both the

access and the recreation area must be under public ownership. The area must be large enough to support public recreation.

44. Channels can provide numerous opportunities for many types of water-based recreational activities, and the presence of flowing water in a natural or seminatural setting enhances activities such as hiking or photography that do not necessarily require flowing water. Factors for evaluation of recreational resources are given in SCS (1977). Different factors apply for each specific recreation activity. For example, channel width, depth, and velocity are important for canoeing and tubing.

Flood-Control Modification Alternatives*

45. Alternative designs should be tailored to the site and project objectives. In general, however, modification schemes which least interfere with the natural stream channel have the least adverse environmental impact. Accordingly, nonstructural measures such as flood proofing, evacuation, etc., have less impact than structural channel modification. A hierarchy of modification alternatives ranked from least to greatest impact is as follows:

- a. Selective clearing and snagging.
- b. Clearing and snagging.
- c. Levees with no channel modification.
- d. Levees and a floodway channel for high flows, with normal and low flows in the existing channel.
- e. Following existing alignment, using the lower portion of the existing channel for normal flows and excavating berms to add capacity for high flows.
- f. Channel enlargement and alignment.
- g. Channel lining.

Of course, most flood-control projects involve mixes of the above alternative measures, and individual situations may differ from the above general hierarchy. Concepts for environmental features presented in Part IV of this report may be used to tailor project design to meet the environmental objectives.

---

* Harrison 1981.

Stability Design*

46. Design of stable channels is a complex subject beyond the scope of this document. There are different schools of thought, and stable channel design is far from being an exact science; however, the following considerations may be helpful in preliminary design. A channel design team should make full use of all knowledge gained from the geomorphologic study described above. Careful investigation of the stream's present and past regime will facilitate estimation of the stream's response to channel modification. Full recognition of existing stability problems within the basin can help to avoid serious instability problems.

Channel alignment

47. In general, the existing unaltered alignment is the best one from a stability standpoint. Channel straightening should be minimized, since the existing grade, portions of the existing stream channel, and riparian vegetation can be preserved by following the existing alignment. However, in many cases other constraints and objectives call for radical realignment or relocation.

Cross section

48. The channel cross section should be modified for low flows as well as high flows. A plot of velocity versus discharge for the modified channel should match the plot for the natural channel as closely as is practical, particularly at the lower discharges. A velocity duration curve may be used instead of velocity versus discharge if the hydrograph is modified by upstream reservoirs. This approach to cross-section design helps to maintain the sediment transport characteristics of the existing channel. A low-flow channel is often useful in this regard.

49. Extremely narrow cross sections tend to produce excessive velocities and require more bank stabilization and grade control. Sections that are too wide usually experience sediment deposition and result in excessive maintenance costs to retain capacity. In general, a

---

* Harrison 1981.

stream that is widened will deposit berms at the toe of the constructed bank. An estimate of the input sediment load and the trap efficiency of the channel are useful in estimating the maintenance requirements for a widened channel (U. S. Army Engineer District, Kansas City 1972).

Channel grade

50. Channel realignment is usually associated with an increase in grade. Typically an increase in gradient is accompanied by upstream degradation and downstream aggradation, with a resultant decrease in grade (Parker and Andres 1976, Yearke 1971) (Figure 9). If straightening is necessary, natural grade may be preserved in the excavated

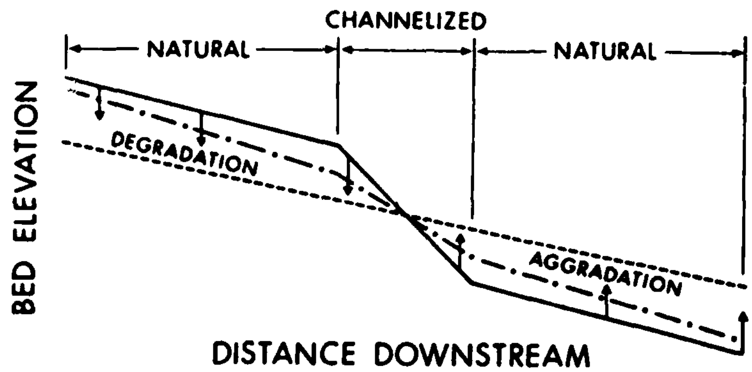


Figure 9. Schematized general aggradation and degradation (Parker and Andres 1976)

channel using drop structures. Drop structures may also be required at the upstream terminus of the project and on tributaries. Schumm (1972) used laboratory experiments to show that channel form, meandering or braided, may change when a threshold value of slope is exceeded. Typically a straightened meandering channel will become a muc! wider braided channel when the critical slope is exceeded.

Grade control

51. The design team must make adequate provisions to ensure channel stability. A stable grade is of primary importance since bank stability is impossible without bed stability. A rough idea of the potential for bed degradation can be obtained by plotting the natu: thalweg profile downstream of the project and extending it upstream

through the modified reach. The difference between the extended profile and the design profile is an indication of the potential for degradation.

52. If the potential degradation is unacceptable, grade control structures may be needed. A certain amount of degradation may be acceptable or even advantageous. If bank sloughing is not too serious, degradation can increase flow capacity and improve drainage of nearby areas. However, degradation can necessitate grade control on tributaries, modification of bridges, and removal of eroded sediment that has redeposited in the channel. Degradation can also damage aesthetic and ecological resources and threaten structures adjacent to the channel.

Bank protection

53. Bank protection may be needed to insure channel stability. Stability of the toe of the bank is required for upper bank stability, and in some cases protection of only the toe may be sufficient. To determine the need for bank protection, the design team should consider and weigh factors that make the bank unstable. Velocities are one indication of erosion potential; ice and trash attack also cause bank erosion. Additional causes of bank failure include sloughing of saturated cohesive banks incapable of free drainage after rapid drawdown, liquefaction of saturated silty and sand soils, erosion by seepage out of the bank, and erosion due to wind- or boat-generated waves. Newly constructed raw banks will erode faster than seasoned banks. Areas of local high velocity and turbulence, such as the outsides of bends, areas near bridges and other structures, and channel contractions, may require protection even if most of the channel does not. Special attention is also needed when a deposit of highly erodible material is exposed in the bed, banks, or on floodway berms. These areas may be treated by blanketing them with clay and then seeding or placing riprap. Streambank protection is covered thoroughly by Keown et al. (1977) and OCE (1978 and 1982).

Side drainage

54. Side drainage normally should not be allowed to flow over banks uncontrolled as this can lead to slope erosion and the incision of tributaries and ditches, particularly if the channel has been

deepened. Local side drainage should be conveyed to tributaries or a simple drop structure and then introduced into the channel. Drop structures may also be necessary for tributaries. Simple drop structures may be built of gabions (Figure 10). A small channel made of

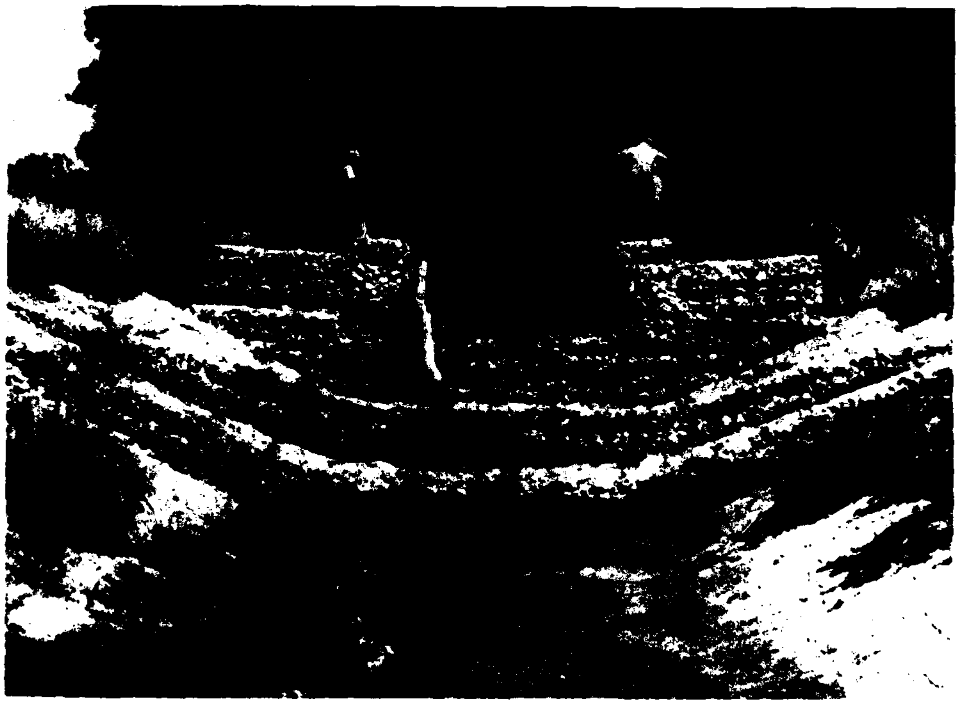


Figure 10. Gabion drop structure for side drainage, Little Blue River Flood Control Project, Missouri

slush-grouted riprap is sufficient in some cases to carry local inflows down the slope. This channel should be protected from underseepage at the top of the slope (the head end of the channel) with a concrete cutoff wall and from undercutting at the downstream end by a toe. Slush-grouted riprap is prone to early failure due to its lack of flexibility, and therefore other types of lining, such as ungrouted riprap on a gravel bed, may be more economical over the life of the project. Shallow sediment traps just upstream of side drainage inlets have been proposed for an SCS channel project to reduce concentrations of sediment and associated pollutants (Figure 11). These traps will require maintenance, however (Walker 1979). A natural stream with a perched channel and/or natural levees can present special drainage problems.

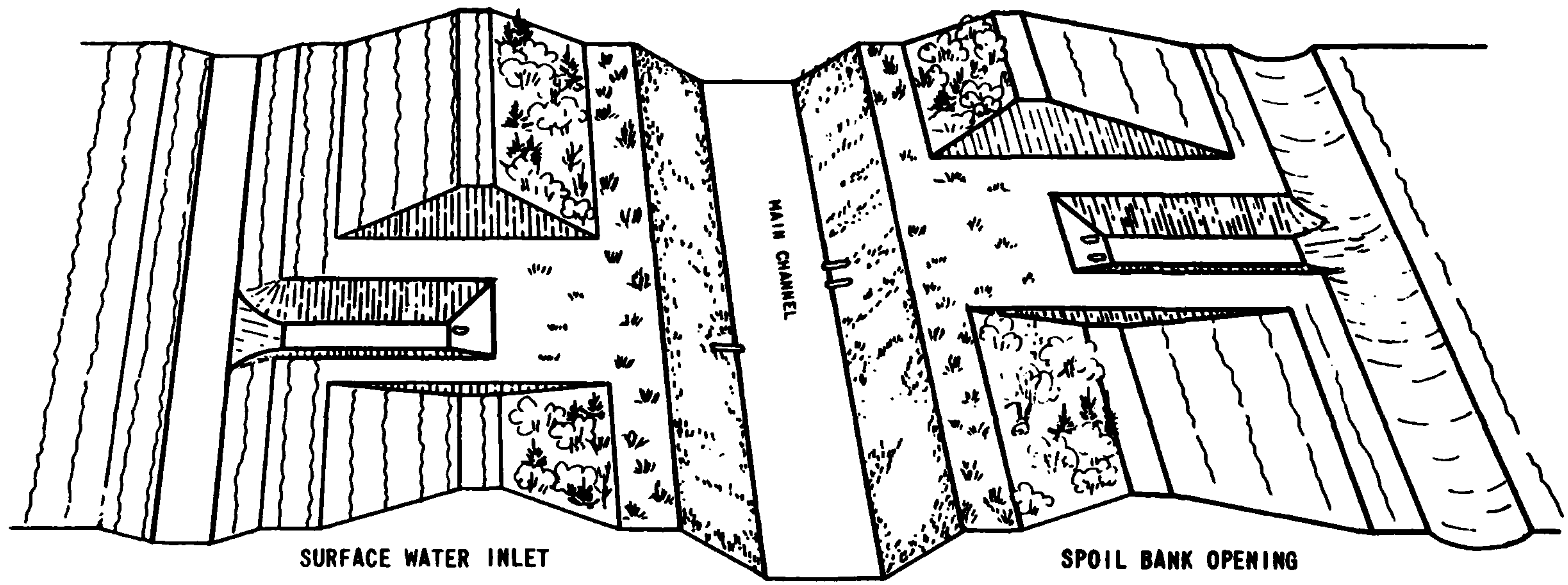


Figure 11. Side drainage inlets with sediment basins (Walker 1979)

Erosion control

55. Sediment input to the channel from construction areas can be minimized by prompt seeding and mulching of finished areas such as floodways, disposal areas, levees, and channel side slopes. Extensive literature is available describing control of sediment around construction sites. Animoto (1978) is a typical reference. Widely used methods include seeding and mulching, sediment ponds, straw bale check dams, and the use of special mats and fabric to stabilize slopes long enough for vegetation to become established. Consideration should be given to building floodways with enough capacity to allow some natural vegetation to grow there. Additional information on vegetation is presented in Part IV of this report.

PART IV: ENVIRONMENTAL FEATURES FOR FLOOD-CONTROL CHANNELS

Introduction

56. An increasing awareness of the adverse environmental impacts of channel modification has prompted several attempts by channel designers to incorporate environmental considerations into modification schemes. Several of the techniques that have been used with some degree of success are described below. Design criteria or valuable aspects gleaned from previous applications are presented for some of the methods. However, since only limited experience exists for most of the methods and since each channel modification project is unique, persons using this information should do so with care. This report will aid, but not replace, the ingenuity of an interdisciplinary team.

57. Information presented below is limited to that which pertains to the channel modification alternatives clearing and snagging; channel enlargement, alignment, and relocation; and channel paving and grade control. Nonstructural methods of flood protection and flood control such as floodplain management, land treatment, zoning, floodproofing, flood warning, and the like are beyond the scope of this report.

General Considerations

58. The environmental features or methods which are incorporated into a particular project to reduce adverse impacts are employed to meet objectives established in the planning stage. Environmental objectives for a project are usually selected early in the planning process and are based on many different considerations; e.g., economics, the scarcity or value of the existing habitat, public interest, and the desires of the local sponsor. Environmental objectives for flood-control channel projects should be established to protect and maintain the ecological integrity and cultural, archaeological, and aesthetic resources of the stream and associated riparian areas as much as is practical.

59. Channel stability is important for both environmental and

structural reasons. Channel project designs must include adequate provisions for grade control, prevention of headcutting at points of tributary inflow, prevention of excessive bank erosion and failure, and control of overbank drainage if ecological and aesthetic objectives are to be met.

60. Riparian zones and streambanks must be protected against additional clearing, modification, or abuse by individual landowners after construction is completed. Preservation of unaltered tributaries, receiving water bodies, or unaltered reaches of the modified stream can provide refuge for fish and wildlife during periods of environmental stress. Natural overbank flooding adjacent to an unaltered reach can preserve a riparian community, although structural measures may be required to direct floodwaters back to the altered channel to avoid downstream damages. Proper location of these unaltered zones can significantly reduce aesthetic degradation.

61. Environmental objectives are usually best attained when channel layout, design, and construction are accomplished with meticulous attention to the details of the existing site. Rare or exceptionally large trees and unique geological features can sometimes be preserved by making the design process a procedure of tailoring the channel to the site, rather than a gross, general analysis of only structural, geotechnical, and hydraulic considerations.

62. Since many environmental features for flood-control channels are unorthodox and innovative, construction contractors may be unaware or unfamiliar with their significance. Effective implementation of environmental features during the construction and operation of a project is a must if environmental objectives are to be met. A preconstruction meeting in which environmental features and objectives are explained to Federal construction inspectors and the contractor's representatives may be helpful in this regard. The inclusion of environmental features in channel projects generally requires closer supervision and inspection of construction work and substantial financial penalties for nonperformance.

Clearing and Snagging

63. Conventional clearing and snagging normally consists of the removal of all obstructions from the channel and all significant vegetation from an area of specified width on both sides of the channel using bulldozers, draglines, or other heavy equipment. Obstructions removed from the channel include dead trees, stumps, logs, boulders, solid waste such as junked vehicles, and sometimes sediment. Clearing and snagging is only a short-tern expedient with temporary effects unless followed by periodic maintenance to prevent reestablishment of vegetation.

64. The degree of flood reduction attainable by clearing and snagging depends on how obstructed the stream is before modification. Other factors such as channel gradient and sediment load are also important. Obstruction of a channel by a fallen tree or snag can direct the current into a bank. Resulting undercutting and bank failure may cause additional trees to fall into the channel. Sediment bars may form in zones of low velocity upstream or downstream of an obstruction, further retarding flow.

65. Selective clearing and snagging is the process of removing only the trees and obstructions that significantly impede flow. Construction equipment and methods are controlled to preserve other vegetation and naturally occurring structures. The goal of selective clearing and snagging is a channel with no major obstructions; no excessive erosion or deposition; smooth, gradual bends; banks lined with trees and shrubs; plentiful shade over the channel; and abundant and diverse food and habitats for wildlife (Herbkersman undated).

66. Selective clearing and snagging offers several advantages. For example, an adequate shade canopy prevents invasion of the channel by cattails, willows, and similar invader vegetation during low flows. These fast-growing species can quickly become established in exposed channel beds with low normal flow velocities and can trap sediments. Streams often respond to the resultant increased hydraulic roughness by widening and forming a central bar (Figure 12). Inadequate shade over

Figure 12. Effects of tree removal on channel stability; i.e., central bar formation, divided flow, and channel widening resulted when bank vegetation was cleared and invader vegetation became established in the channel during low flow

the channel therefore increases maintenance requirements for some channels.

67. From a maintenance standpoint, the ideal growth of streambank vegetation is a stand of large trees and shrubs a short distance from the top of the bank and no significant vegetation in the channel (Figure 13). The trees should be large enough and close enough to the channel to shade out invader vegetation, yet far enough back from the top bank to be stable and not easily undercut. Trees should be well spaced so they will not stifle one another's growth. Trees prone to fall into the channel or which have little habitat value are not desirable.*

68. Another advantage of selective clearing and snagging over conventional practice is the preservation of aquatic and terrestrial

---

* Personal communication from George Palmiter, Montpelier, Ohio, May 1981, to the author.

Figure 13. Effect of trees on channel stability; i.e., modified channel has well-developed riparian vegetation which shades out invader vegetation and enhances bank stability

habitat. The ecological significance of riparian vegetation is discussed in Part III above. Marzolf (1978) discusses impacts of clearing and snagging on fish and wildlife resources. Preservation of sturdy riparian vegetation also inhibits some types of bank failure and erosion (Allen 1979).

69. Both selective and conventional clearing and snagging are frequently applied to obstructed channels to restore an earlier, greater flow capacity. Channels can become obstructed by excessive upland erosion, disposal of refuse and solid waste into the channel, and logging; or a large number of riparian trees may suddenly die and fall in the channel (as the result of an epidemic of Dutch Elm disease, for example).

70. A lack of channel maintenance sometimes allows riparian vegetation and aquatic and terrestrial habitats to recover. When such a channel is finally maintained, the environmental impacts may be almost as significant as the original modification. Selective clearing and

snagging is useful in such a situation. An analysis of the stream channel and drainage basin can reveal the causes of flow-capacity reduction in each reach; e.g., sediment deposits from excessive upland erosion, logjams, or invasion of the channel by woody species. Cooperation among the Federal agency, the local sponsor, and the contractor can lead to development and implementation of guidelines or specifications to remove the major obstructions with minimum adverse impact. Preventive maintenance, such as stabilizing badly eroding banks or removing leaning trees likely to fall into the channel, is also an important part of this type of work.

71. Selective clearing and snagging specifications can be written to direct that only certain types of equipment may be used. For example, snags, drift, debris, and leaning trees can be removed from the channel using floating equipment. A small portable barge or raft equipped with a crane may be used in streams of adequate width and depth to move snags to preselected points on the bank. Log skidders may be then used to move the debris to disposal points (U. S. Army Engineer District, Mobile 1978; Herbkersman undated). If the stream is too shallow for floating equipment, yet has a firm bed, regular heavy equipment may be used in the channel itself; this approach will probably increase short-term construction-type impacts, but longer term effects on riparian vegetation will be less severe than with conventional methods. Another alternative is to utilize laborers in small boats to remove snags. Laborers can cut up some snags with chain saws and hook cables to others which can then be winched or pulled from the channel by a log skidder, small tractor, or team of draft animals. The Bantam C350 dragline and the John Deere 450G tractor with winch have been used successfully for this type of work.* Safety considerations are of primary importance when using labor-intensive methods (Herbkersman undated).

72. Selective clearing and snagging specifications may also dictate the size and species of riparian trees and descriptions of snags

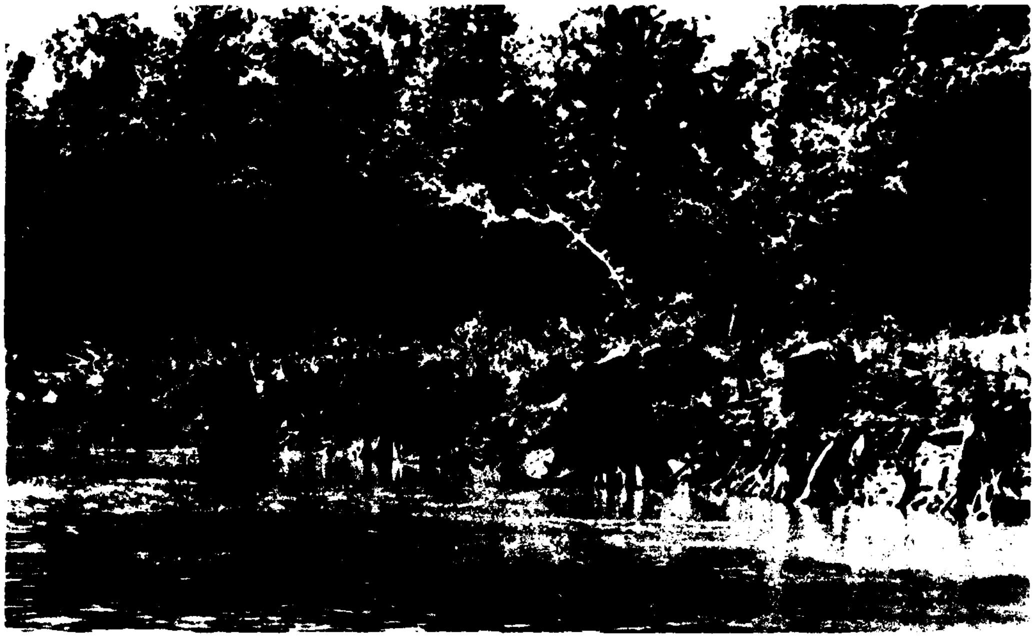
---

* Letter, dated 25 March 1980, from Thomas S. Talley, U. S. Fish and Wildlife Service, Cookeville, Tenn., to Colonel William H. Reno, District Engineer, U. S. Army Corps of Engineers, Memphis, Tenn.

that are to be removed or left in place. A stocking rate, or a number of trees per unit area, may also be specified. The Vicksburg District (U. S. Army Engineer District, Vicksburg undated) has used selective clearing and snagging specifications for overbank clearing which dictate that selected trees be left undisturbed and undamaged. Selected trees include cypress trees, nut-producing trees, and all trees less than 4 in. in diameter or greater than 12 in. in diameter with the exception of willows and cottonwoods. Diameters are measured 3 ft above the ground line on the landward side of the tree. Smaller trees are selected for preservation also to maintain a minimum of ten trees per 1/4 mile along each bank for any given reach and are chosen in such a manner as to create a balanced appearance on each side of the channel centerline. The contractor is further instructed to avoid disturbing or removing cypress and/or nut-producing trees for movement of equipment or for other operations that are done for his convenience. Frequently the stumps of trees that are removed (Figure 14) and logs and snags partially embedded in the channel that are aligned with the flow may be left in place to provide aquatic habitat.

73. Disposal of logs, brush, and other debris produced by clearing and snagging operations may be controlled for environmental purposes. Logs and brush may be used to build revetments to protect eroding banks or small "spur dikes" to direct the current away from eroding concave banks. The spur dike must be secured to a stake or a tree with wire so it will not be washed away during high flows (Herbkersman undated); sediment deposition soon locks the brush in place. Higher velocities may require that brush be secured with cables and deadmen, or may prohibit the use of brush altogether. If dikes are structurally unsound, they may accelerate rather than prevent bank erosion. Debris may be tied or otherwise secured in piles or windrows on overbank areas to provide terrestrial habitat. Other debris disposal alternatives include burying, burning, and sale for lumber or firewood.

74. Example selective clearing and snagging guidelines are given by McConnell et al. (1980) and are reproduced by Shields and Palermo (1981). These guidelines were specifically developed for the Wolf River,



(Courtesy of C. A. McConnell and the Soil Conservation Society of America)

Figure 14. Selective clearing and snagging. Stumps of cleared trees are allowed to remain in accordance with selective clearing and snagging guidelines written for the Wolf River, Tennessee. Retention of a limited number of trees for shade and habitat would have been even more desirable

Tennessee. Similar guidelines have been developed and utilized for several other projects in western Tennessee, western Kentucky, and North Carolina.*

75. A more comprehensive approach to clearing obstructed channels is presented by Willeke (1981) and Herbkersman (undated). These authors document an approach developed by Palmiter for relieving chronic, low-intensity flooding problems and certain types of streambank erosion in partially obstructed channels. Readers desiring additional detail about the Palmiter approach should consult these references. Audiovisual educational materials for training personnel to use the Palmiter techniques are also available.

---

* Personal communication from Thomas S. Talley, U. S. Fish and Wildlife Service, Cookeville, Tenn., July 7, 1981, to the author.

76. The Palmiter approach consists of six steps: (1) logjam removal, (2) protection of eroding banks by building spur dikes from brush and debris, (3) removal of sediments deposited due to logjams, (4) planting cuttings of willows or other flood-tolerant species in sediments deposited in and around brush spur dikes and along the bank where there are no trees or shrubs, (5) removal of trees and stumps that are likely to fall into the channel and become obstructions, and (6) maintenance. Work is done by crews of laborers using small boats or canoes, chain saws, rakes, axes, and other hand tools. Occasionally tractors or draft animals are required to maneuver heavy logs or stumps.

77. The Palmiter approach is best employed as a total entity, rather than applying the techniques piecemeal. A careful survey of the channel by a trained individual is necessary to determine the applicability of the Palmiter approach to the site in question. Work must be planned for each reach; general guidelines and specifications are usually infeasible. Work to be done may be sketched on maps or photographs.

78. Even when clearing and snagging is done with conventional heavy equipment such as draglines, work can be planned to leave intermittent parcels or clumps of trees undisturbed. One concept is to clear an equipment travelway of minimal width (20 to 30 ft) adjacent to the stream and allow additional clearing for disposal areas only if already cleared areas are unavailable. Disposal areas can be placed at irregular intervals to preserve outstanding individual trees and to avoid an unnatural appearance for the completed project. Another approach is to use cleared areas outside of the riparian vegetation belt for travelway and to approach the stream at right angles only at points where channel blockages must be removed.

Channel Enlargement and Alignment

79. The flow capacity of a waterway may be increased by enlarging the cross-sectional area. Channel alignment often accompanies enlargement because a straighter, shorter channel saves excavation costs and is more hydraulically efficient. Modified channels are usually realigned

to avoid local bank erosion in sharp bends. Major environmental impacts result from the loss of stream length; the removal of riparian vegetation; the removal of natural substrate; the use of regular, uniform channel geometry; channel instability; and shallow depths at low-to-normal flows. Most environmental features for modified channels are aimed at alleviating these conditions.

Modified cross sections

80. The undesirable biological and aesthetic impacts of a regular trapezoidal channel can be reduced by using modified cross sections, such as single-bank modification, floodways, low-flow channels, and combinations of these. The basic objectives of most of these approaches are to preserve or reproduce the physical characteristics of the natural channel and to increase the habitat diversity and visual diversity of the completed channel.

Single-bank modification

81. For single-bank modification the existing channel alignment is followed, and the channel is enlarged from one side only (Figure 15). An effort is made to leave the other bank untouched. However, if a dragline situated on the modified bank is used to deepen the channel, tree limbs or trunks overhanging the zone of excavation may have to be removed to accommodate the dragline boom. A hydraulic backhoe can operate in a smaller space than a dragline can and thus may be preferred for smaller channels. Trees and snags on the unconstructed bank that are obstructing flow or that are in immediate danger of falling into the channel are intentionally removed, but this work is done from the modified bank or with manual tools. The snags or trees to be removed are marked by an interdisciplinary team to insure consideration of both engineering and ecological factors. Modification may be restricted to the north or east banks to preserve summer afternoon shade on the south and west. The location of existing stands of trees should also be considered in determining which side is to be modified. Even on the modified bank, clumps of valuable trees can be preserved at irregular intervals. The aesthetics of the project may be improved by alternating construction from one side to the other at short, irregular intervals; road crossings

a. Praire Creek, Indiana

b. Little Blue River Flood Control Project, Missouri

Figure 15. Single-bank modification

make good points to change sides, both from the standpoint of construction equipment access and project aesthetics. Hydraulic considerations should also play a role in determining which side should be modified and where changeovers should occur. For example, it may be desirable to modify the insides of bends and preserve vegetation on the outsides for bank stability.

82. To be effective over the life of the project, single-bank modification must be coupled with continuing protection of the preserved and planted vegetation. A permanent easement approximately as wide or wider than the channel on both sides of the channel provides an effective buffer strip. The buffer strip on the modified bank can be planted or allowed to revegetate naturally. Buffer strips may be marked by fences when livestock are present, or by a windrow of soil or a line of marker posts. Clearly marking the buffer strip boundaries reminds farm equipment operators and others of the easement and prevents some violations.

83. Additional factors to consider for single-bank modification include effects on construction and maintenance costs. Single-bank modification may be more expensive than conventional channel work if the contractor is forced to make more frequent channel crossings with heavy equipment or travel greater distances due to restricted access. Maintenance costs will be increased if trees and other debris fall into the channel from the natural bank. Channel modification may lead to an increased rate of erosion of the natural bank, undercutting trees and requiring toe protection. On the other hand, single-bank construction will reduce costs because construction will be confined to one side of the channel through a given reach and less clearing and less revegetation of disturbed areas will be required. Maintenance for small channels may be reduced due to the effects of shade from the unconstructed bank on invader vegetation.

Floodways

84. Low flows in a natural stream normally occupy only a relatively small portion of the area between the top banks. A small rise fills the channel, and during a flood the stream overflows the normal

channel and uses the floodplain as a high-flow channel. A constructed floodway mimics nature because separate channels are provided for high and normal flows. It is good practice wherever possible to use the existing natural channel for normal to low flows, and to excavate the high-flow channel adjacent to the natural channel. In some cases the high-flow channel is constructed straight through the channel trace through the valley, following adjacent to the channel in straight reaches and crossing the necks of meanders (Figures 16 and 17). A floodway

Figure 16. Floodway channel across meander neck, looking upstream, Little Blue River Flood Control Project, Missouri

channel project can be more visually pleasing than and provide superior habitat to a conventional enlarged channel. In addition, when not in use, high-flow channels may support secondary uses, such as recreation or wildlife habitat.

85. The feasibility of a floodway is governed in part by the topography on either side of the stream. There must be enough relief present to allow excavation of high-flow berms at an elevation intermediate between the natural channel and the surrounding floodplain, yet not so much relief that excavation costs are excessive. A combination of

Figure 17. Downstream confluence of floodway cutoff and natural channel (grade control sill in floodway is obscured by vegetation), Little Blue River Flood Control Project, Missouri

levees and floodway excavation may be best in certain situations.

86. The elevation of the high-flow berm (the floodway invert) is a key design parameter. For a given cross-sectional area, higher high-flow berm elevations require a wider floodway and thus increase land requirements. Berms placed too low will be inundated too frequently, hindering secondary uses. Establishment and maintenance of grass on the wet, muddy berm will also be difficult. If the stream carries an appreciable sediment load, deposition may occur on the berm as part of the fluvial response to a wider cross section. Sediment deposition on the berm may further hinder establishment of desirable grasses and make the berm uneven and difficult to mow. Maintenance costs will therefore be increased. For these reasons, reliable discharge frequency information is a necessity for proper design of a floodway.

87. Special consideration must be given to grade control for a floodway channel. The grade of floodway cutoffs across meander necks

somtimes must be controlled by grade control sills at the downstream end to prevent rapid headcutting through the floodway and subsequent diversion of all flows through the floodway channel (Figure 17). A floodway channel is particularly vulnerable to excessive headcutting from the downstream end during and right after construction before vegetation is well established. A grade control sill might be placed at the upstream end of the floodway cutoff and the cutoff channel excavated down to the same elevation as the natural channel invert to allow backwater to permanently fill the floodway cutoff for recreational and ecological purposes. This approach would necessitate additional excavation and might promote sediment deposition in the floodway. No instances where this approach was used were found in the literature.

Low-flow channels

88. Low-flow channels may be used with conventional enlarged channels or with floodways. The low-flow channel carries low-to-normal flows and prevents excessive deposition in the enlarged channel. Deposition or erosion occurs in constructed alluvial channels because the fluvial system adjusts itself to the configuration dictated by its discharge and sediment regime. The low-flow channel may be composed of the original natural channel, a newly excavated channel, or some combination of the two.

89. Properly designed low-flow channels reduce adverse impacts on the aquatic community because they provide desirable depths and velocities at low-to-normal flows. When the existing natural channel is used as a low-flow channel, the existing substrate, instream structure, vertical relief (pool-riffle system), and alignment can be preserved; but it is essential to exclude construction equipment from the natural channel. Fording of equipment and vehicles should be held to a minimum by constructing temporary crossings.

90. If a new low-flow channel is to be constructed, there are three major considerations: stability of the low-flow channel, aquatic habitat within the low-flow channel, and overall project aesthetics. Consideration should also be given to reproducing the gradient, flow capacity, cross-sectional shape, sinuousity, velocity distribution, and

bed material of the unaltered stream channel, since in most cases this approach addresses all three of the above considerations. Rates of lateral migration acceptable for unaltered channels may be unacceptable for low-flow channels since they are to be confined within a larger structure. Although some initial erosion and deposition is to be expected, excessive channel migration must be avoided by using streambank protection at critical points. Depths at low flows should be adequate for aquatic habitat. Wide, shallow flows are unsatisfactory for many aquatic species and cause higher water temperatures. A meandering channel with pools and riffles, even within the confines of a larger channel or floodway, is more visually diverse than a uniform cross section.

91. Reproducing the physical characteristics of natural, unaltered channels in low-flow channels is not always feasible. Reproduction of the natural bend radius of curvature and/or channel sinuousity may lead to excessive land and excavation requirements. Reproduction of the cross-sectional shape may require excessively deep excavation with attendant groundwater problems and grade adjustment problems at upstream and downstream controls.

92. Reproduction of unaltered stream geometry has been successfully applied to stream channel relocation. Hunt and Graham (1975) discuss the construction of two meanders as part of a stream relocation for highway construction in Montana.* The two artificial meanders were designed and constructed to have widths, depths, and cross sections similar to natural, unaltered meanders on the same stream.

93. A study of the constructed meanders showed that they had geometric characteristics and velocity regimes quite similar to the unaltered meanders. Fish of the same size, species, and quantity found in the natural channel were found in the artificial meanders three years after construction.

---

* The Clark Fork River has an average gradient of 5-10 ft per mile ($S = 0.0009 - 0.0018$) and is limited in its lateral meandering by the slope of the sides of the valley. The surrounding terrain is mountainous. A brief discharge record included extremes of 190 and 4450 cfs. The bed material was glacial till.

94. Hunt and Graham (1975) suggest design guidelines for relocated channels which are presented below in slightly modified form:

a. Study the geomorphology of the stream; this may be done using photogrammetry and field observations.

b. Study the hydraulic, topographic, and planimetric conditions of the unaltered stream in the general area of the proposed channel modification to establish design criteria for the new channel.

c. A typical channel cross section based on the hydraulic characteristics of the natural stream should be selected and held constant throughout the curve of a meander to simplify construction. The cross section should be asymmetrical, with steeper side slope and greatest depth on the outside of the bend and a more gradual slope toward the inner bank (Figure 18). This cross section will allow a natural velocity regime to develop and natural patterns of scour and deposition to occur.

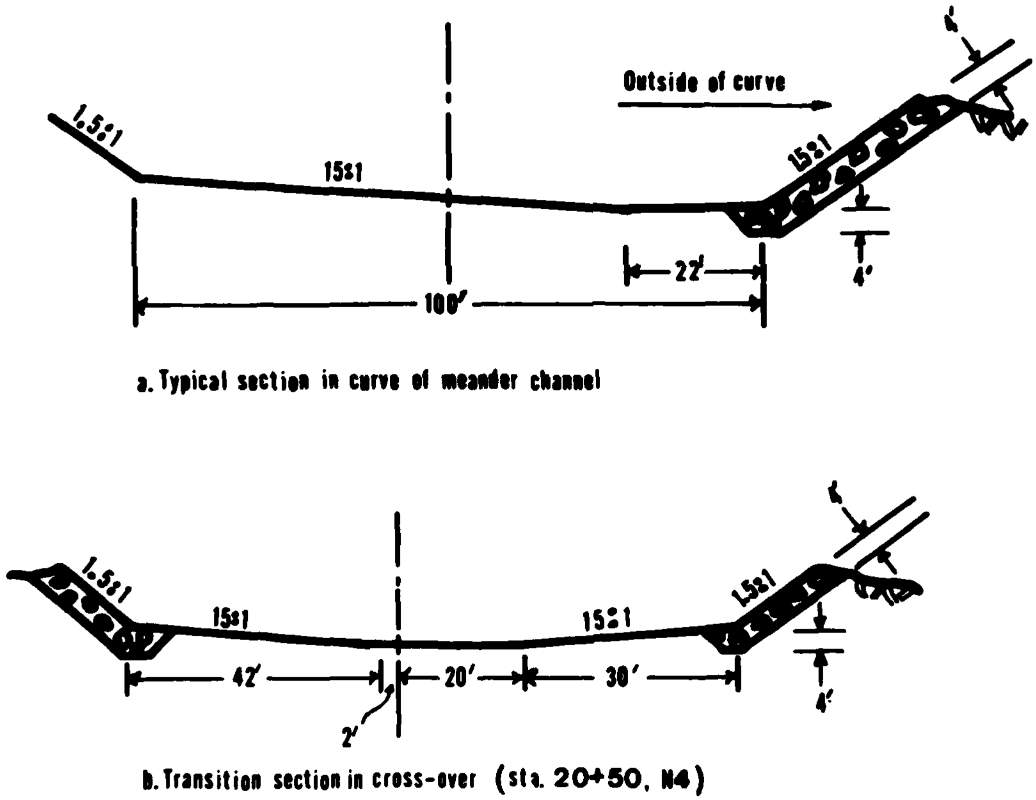


Figure 18. Cross sections for constructed meander, Clark Fork River, Montana (Hunt and Graham 1975)

d. The bed gradient should reproduce the vertical relief of the natural channel. A natural channel with a system of pools and riffles will be characterized by long flat reaches (pools) interspersed with occasional steep segments (riffles). A channel constructed with this type of gradient will more quickly scour and deposit sediments to attain a somewhat natural state. A steep gradient skewed across the stream in the riffle areas should be located just downstream from the inflection points of the meander curve (Figure 19). These riffles will provide crossovers for the thalweg.

95. A more thorough treatment of the design and construction of relocated stream channels is found in a report published by the Federal Highway Administration (1979), Chapters 5 and 7. This document focuses on rocky western streams with salmonid habitat.

Pools and riffles

96. The importance of pools and riffles, or shallows and deeps, to the habitat diversity and aesthetic resources of a stream has been mentioned above. If the unaltered natural stream channel contained pools and riffles, consideration should be given to constructing pools and riffles in the modified channel. The main problem in designing and constructing pools and riffles in a modified channel is creating a system that will maintain itself over a range of events. In unaltered alluvial streams the bed material moves downstream, but it does so in such a way to preserve a pattern of pools and riffles (Leopold, Wolman, and Miller 1964). Conversely, constructed pools tend to fill with sediment and disappear, while constructed riffles or shallow areas are frequently washed out. The frequency and dimensions of pools and riffles in an unaltered stream are interrelated with other components of the fluvial system such as bed material size and gradation, discharge, and channel slope. The complexity of the fluvial system makes design of a stable pool-riffle sequence difficult. Large floods may drastically alter the configuration of any alluvial channel.

97. Study of the characteristics of natural streams has revealed that the ratio of average pool spacing (measured along the channel) to average channel width is between 5 and 7 (Leopold, Wolman, and Miller 1964). Pool spacing varies from one reach to the next, but the mean

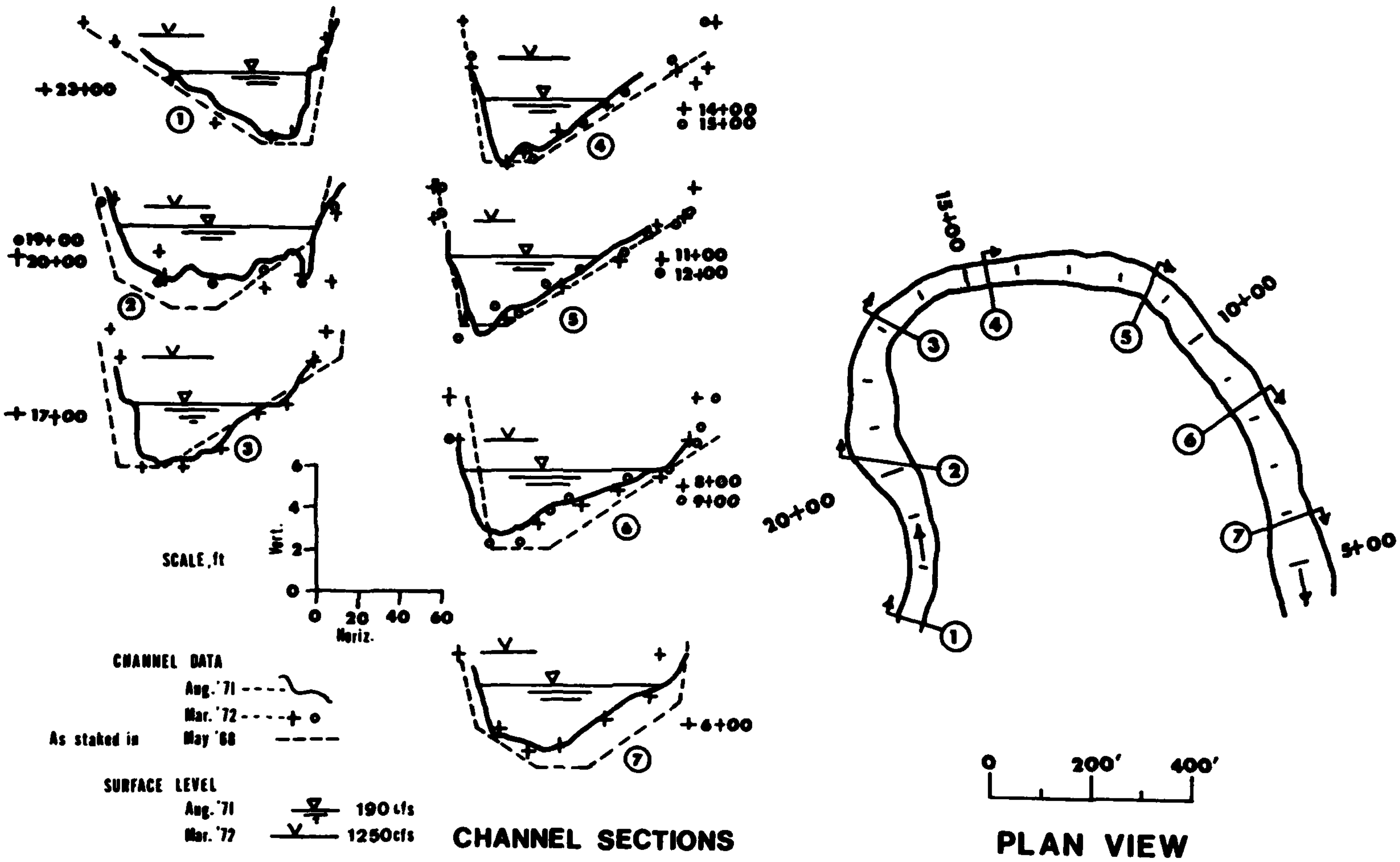


Figure 19. Plan and sections for constructed meander, Clark Fork River, Montana (Hunt and Graham 1975)

spacing over a long reach tends to fall between 5 and 7 even in slightly altered streams. Keller (1978) measured pool-to-pool spacing for seven streams ranging in width from about 30 to 80 ft and with channel slopes of from 0.0010 to 0.0049 (Figure 20). Analysis of variance showed that

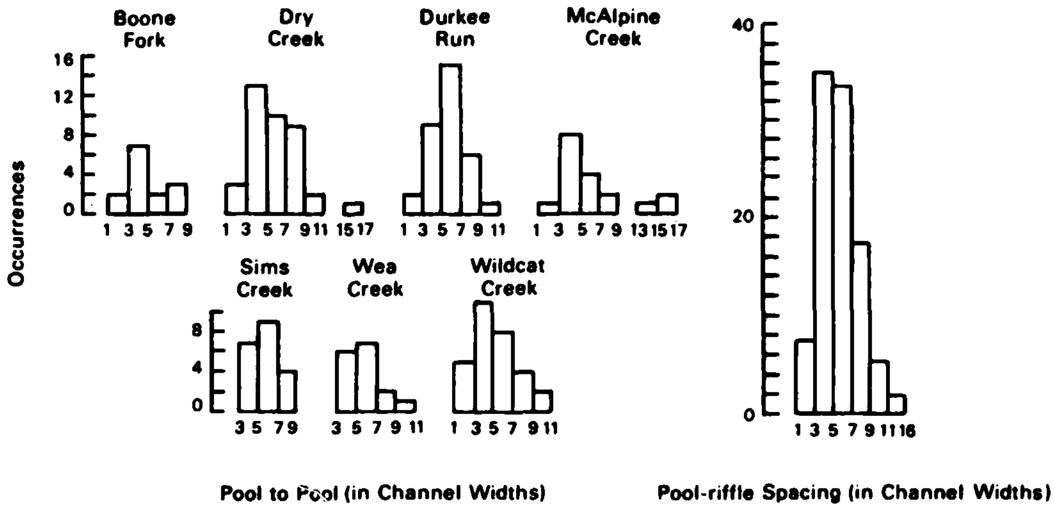


Figure 20. Distribution of pool spacing for seven streams (Nunnally and Keller 1979)

there was no significant difference between the ratios of pool spacing to channel width for natural streams and the same ratios for streams impacted by a variety of human activities including upstream impoundment, urbanization, and straightening. In other words, the fluvial systems maintained a fairly regular, predictable pattern of pools and riffles even under conditions of stress. However, streams enlarged by widening were not included in this analysis, and changes in pool and riffle depths were not examined.

98. Keller (1978) attempted to design and construct a channel enlargement in such a way as to induce the formation of pools and riffles. The subject stream reach was 420 ft long with a 15- to 20-ft bed width and had been enlarged and straightened 25 years previously. For this experiment the channel was cleared of debris and brush and widened slightly. Point bars and scour areas were induced to form in the new channel by constructing the channel with an asymmetrical cross section where a point bar was desired. Regular channel side slopes were 2 times

the height (H):1 time the vertical distance (V), but a slope of 3H:1V was used where a bar was desired. The bars formed adjacent to the 3H:1V banks as planned, and the pool-riffle system thus formed remained stable for more than a year and during four overbank flows. However, at the end of this period the stream bottom was buried by a sudden influx of sediment, the bars were covered with about 1.5 ft of sand and fine gravel, and the pool-riffle system did not recover. This sediment was partially derived from upstream conventional channel modification.

99. A similar experiment on a small trout stream in Scotland met with success (Stuart 1953, as presented in Leopold, Wolman, and Miller 1964). As the stream was dredged with a dragline, piles of gravel were left on the stream bed at intervals 5 to 7 channel widths apart, thus reproducing a natural pool-riffle sequence. The piles were flattened over a period of time and the pool-riffle system thus formed remained stable over many years of observation.

100. Pools and riffles can be constructed in bedrock channels. Stability of the pool-riffle system is obviously easier to achieve with a stationary bed.* A low-flow channel composed of a series of pools and riffles was constructed in the bottom of an enlarged bedrock channel by the U. S. Soil Conservation Service in Indiana in order to provide aquatic habitat during normal and low flows. Prior to construction of the low-flow channel, shallow flows spread across the entire 65-ft width of the enlarged channel, and aquatic habitat was minimal. The low-flow channel as constructed consisted of pools 10 to 15 ft wide and 2.5 to 4 ft deep and riffles 5 to 7 ft wide and 0.5 to 1 ft deep. Both pools and riffles were 50 to 150 ft long with a fairly constant channel gradient of 0.00055. Although the low-flow channel had less capacity than the original unaltered channel, it has remained stable for several years and provided habitat for a diverse fish population.

---

* Even bedrock channels can be unstable in certain circumstances. Emerson (1971) reported that flood control modification of the Blackwater River in Missouri, where bedrock is thin-bedded Pennsylvanian shale, coal, sandstone, and limestone, increased the slope from 0.0016 to 0.0031 and resulted in considerable instability.

101. A system of pools and riffles might be induced in an alluvial low-flow channel of an enlarged flood-control channel using the method of Keller (1978) described above. A system of pools and riffles, or less well-defined alternating deep and shallow zones, may form in time; but it may be desirable to induce formation of zones of scour and deposition for both ecological and aesthetic reasons. Keller (1975 and 1978) suggests the following design criteria:

a. For gravel-bed channels with widths less than 80 ft, pools and riffles should not be constructed with an average slope greater than about 0.005.

b. Channel morphology is related to the ratio of average particle size to the average channel slope. Relatively high values of this ratio usually indicate streams with regularly spaced pools, and low values indicate unstable conditions without regularly spaced pools. Measurements of this ratio on stable, unaltered natural channels can aid in the design of low-flow channels.

c. Pools should have an asymmetric cross section (steeper side slopes on the deep side) and riffles, a symmetric cross section. (This is somewhat similar to the recommendation by Hunt and Graham (1975) presented above.)

d. Pools should be spaced five to seven channel widths apart (center to center).

e. In straight reaches, the deep side of pools should alternate from bank to bank. In bends, the pools should be located so that the deep side is near the outside of the bend.

f. Rapid, drastic changes in average discharge or sediment load such as those caused by drastic land-use change should be prevented.

Water level control

102. Enlarged channels are normally almost empty most of the time. The shallow depths provide little aquatic habitat and lead to higher water temperatures. Willows and similar water-loving species invade the exposed channel bed during low flows, creating a maintenance problem. The massive, empty channel is aesthetically displeasing to most observers, particularly if the channel is paved.

103. These impacts may be addressed by use of various types of control structures to impound water in the enlarged channel. Water

control structures are particularly useful in low-gradient channels. Adjacent wetlands that would be drained by channel modification may also be preserved using levees and water control structures adjacent to the channel (McCall and Knox 1978, Montalbano et al. 1979). Water control structures placed within the flood-control channel must be designed, built, and maintained so that they do not create problems of downstream scour, upstream sedimentation, or reduction of flow capacity under high-flow conditions. In addition, structures should not prevent necessary migrations of aquatic organisms.

104. In some projects unexcavated sections (earth plugs) have been left in the channel to impound water during low flows. Some of these plugs have been protected from scour and erosion by placing riprap or other types of protection. However, these simple plugs frequently cause maintenance problems and experience scour and flanking. In some situations more permanent water control structures may be more effective and have a lower cost over the life oı the project (Ables and Boyd 1969). Design guidance for low-water weirs constructed from sheet piling and riprap is given by Ables and Boyd (1969). This guidance has been used successfully to design a number of water control structures for low-gradient streams. The SCS has experienced success with low weirs in agricultural flood-control channels (the design event has a 3-5 year frequency) in Louisiana. These low weirs are not intended to provide grade control and have virtually no effect on high flows.

105. Water level control may also be accomplished with grade control structures in some situations. Walker (1979) discusses the use of such structures as part of the planned Little Black Watershed project in southern Missouri. Four wet-weir concrete drop structures will be placed in a 100-ft wide channel with a hydraulic gradient of 0.00010 to 0.00015. Water will be approximately 4 ft deep upstream of each structure, and the backwater will extend to the next structure upstream. Total water surface area for the four structures will be about 175 acres. Each structure will have a 1-sq ft port opening near the bottom to permit waterflow and movement of aquatic organisms at low flow.

106. Another type of water level control structure well suited

for use in an enlarged channel is the inflatable dam (Figure 21). Inflatable dams are flexible bags or tubes anchored to a concrete pedestal foundation. The dam can be inflated with water or air to impound low flows, and it can be partially or completely deflated to allow high flows to pass. The inflation of the dam (and thus its elevation) is automatically controlled based on upstream water surface elevation (U. S. Army Engineer District, Detroit 1974).

107. Inflatable dams are commercially available and are made of durable materials, such as neoprene reinforced with several plies of nylon. The fabric is durable enough to resist puncture and the water pressure inside the dam is low enough (4 to 5 psi) that leakage rates are very low if punctures occur. Repairs are simple, and no special tools or skills are required (Detroit District 1974).

108. The Flint River Flood Control/Beautification Project in Flint, Michigan, includes an inflatable dam that maintains a constant water depth of 9.5 ft in a rectangular channel. The dam, constructed for aesthetic and recreational purposes, consists of two water-inflated bags, each 50 ft long and 6 ft high (when fully inflated), mounted on a 3-ft-high concrete sill. During cold weather the bags are inflated with air. Inflation is automatically controlled based on upstream water surface elevation. The dam passes a flow of 200 cfs over the bags when fully inflated. With the dam deflated, the channel has a design capacity of 6000 cfs. Since high flows are not impounded by the dam, there is little extra sediment deposition in the pooled reach (Detroit District 1974). Operational difficulties have been reported for inflatable dams installed in sediment-laden streams.

Preservation of severed meanders

109. Realignment of natural meandering streams results in cutting off meander loops. All streamflow may be diverted into the constructed channel and the abandoned meander or oxbow cleared and/or filled. The net result is a loss of aquatic habitat and overall habitat diversity. Even if the severed meander is not deliberately filled, it is usually either isolated from the main channel by sediment deposition or drained. The small pond thus formed usually has insufficient local inflow to

Figure 21. Inflatable dam. Water-inflated bags automatically regulate flow to maintain constant depth upstream, Flint River Flood Control/Beautification Project, Flint, Michigan

maintain adequate water quality for a healthy aquatic community. The old meander declines biologically, gradually fills with sediment, and becomes terrestrial habitat.

110. Severed meanders can be maintained as small ponds or wetlands adjacent to the flood-control channel (Figures 22 and 23). The preserved meander normally will no longer provide a stream-type habitat, but the resulting backwater habitat it does provide can be valuable if managed properly. The land inclosed by the severed meander can be managed to provide terrestrial and riparian habitat, and the whole oxbow area can be an ecological, aesthetic, and recreational resource. Even if the fishery in the oxbow declines due to sedimentation, stagnation, poor water quality, or dewatering, the old channel and the land it encloses will provide habitat useful to waterfowl and other birds, small mammals, reptiles, and amphibians.

111. Cutoffs are frequently constructed across meander loops on waterways open to commercial navigation. Significant progress has been made in extending the life of severed meanders on navigation projects by blocking the upstream end and building specially designed dikes to maintain a narrow entrance at the downstream end. The problem of cutoff preservation on these large waterways is somewhat different from cutoff preservation along flood-control channels. Flood-control channel projects typically involve a greater increase in channel size than navigation projects. Under normal flow conditions, the water surface elevation in an enlarged flood-control channel may be lower than the channel invert of an adjacent severed meander. Channel deepening due to channel degradation can also cause this problem. In navigation projects it is desirable to maintain as much flow as possible in the main channel in order to transport sediment and provide adequate depths during low flows, while additional off-channel flow capacity is normally acceptable for flood-control channels.

112. If the modified channel is constructed at or allowed to degrade to an elevation lower than the cutoff meander, it will be necessary to construct channel blocks to impound water in the old meander. A culvert or weir can be placed in one or both channel blocks to allow

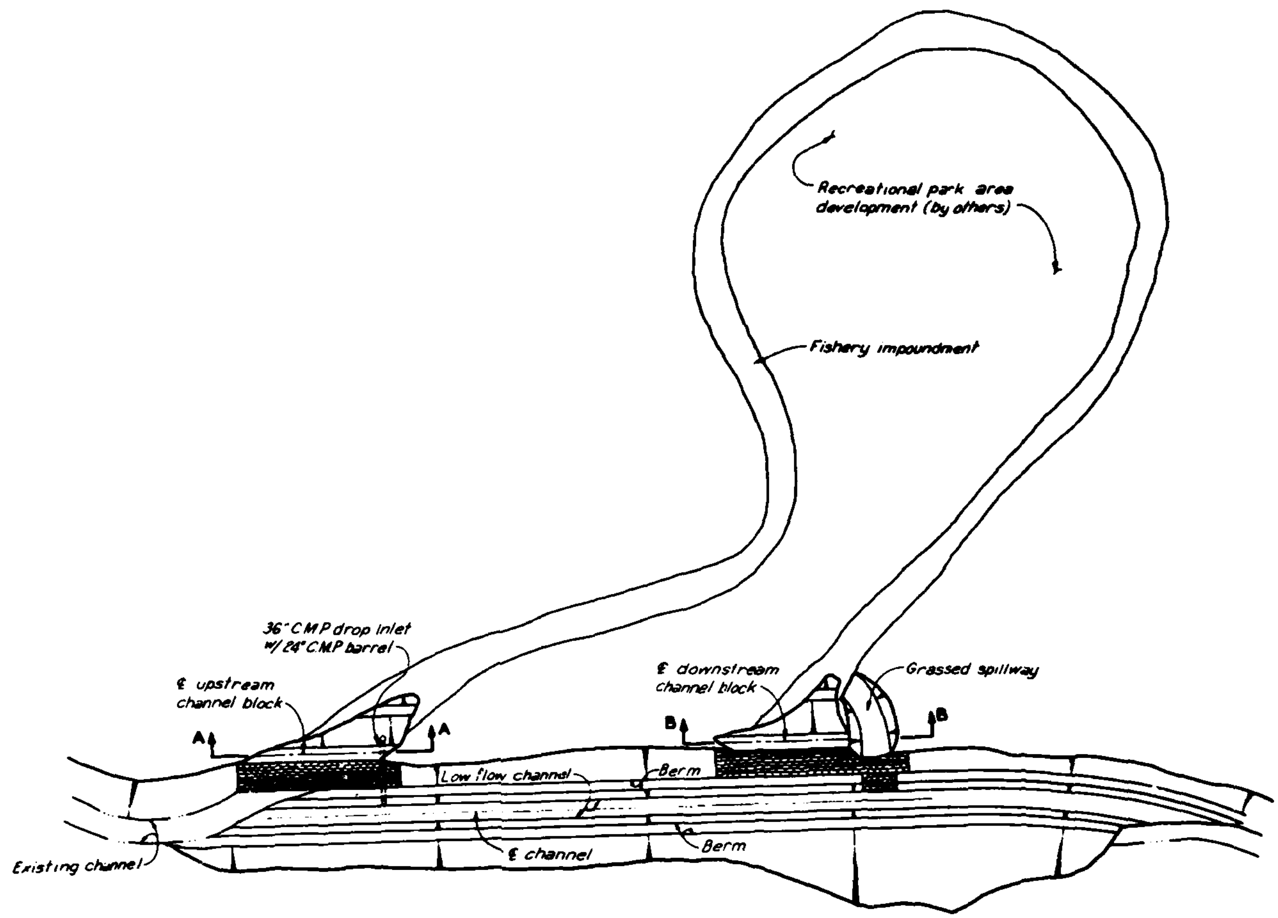


Figure 22. Plan of fishery impoundment constructed by blocking both ends of a severed meander. Corrugated metal pipe (CMP) drop inlets allow flow from the impoundment to the flood-control channel when the impoundment water surface is high enough, Little Blue River Flood Control Project, Missouri

Figure 23. Impoundment made from severed meander, Little Blue River Flood Control Project, Missouri

flow between the two channels during high flows. Several types of hydraulic structures have been constructed to connect flood-control channels and severed meanders including simple rock weirs and culverts through the closure embankments. Flap-gated culverts may be used to pass water from the flood-control channel to the oxbow during high flows but prevent any backflow from the oxbow to the main channel (U. S. Army Engineer District, Memphis 1979). All types of hydraulic structures for oxbows are subject to blockage by debris and sediment and should be designed accordingly, using trashracks, standpipes, etc., and frequently maintained.

113. If the modified channel is not significantly deeper than the old meander, low to normal flows may be passed through the severed meander by not excavating the flood-control channel to full depth through the cutoff reach. An earthen plug will thus block the flood-control channel during low to normal flows, and will be overtopped by higher flows (Memphis District 1979). The portion of the flood-control channel across the meander thus becomes a floodway. Riprap protection and/or

grade control may be necessary at either end of the plug to prevent scouring. The height of the plug is determined by hydraulic and ecologic considerations. The old meander channel will provide additional flow capacity for flood control. Retention of the plug in the flood-control channel reduces the amount of excavation. The use of this scheme may be limited in some circumstances by local topography and land use.

Sediment traps

114. Channel excavation is often accompanied by increased sediment loads, both during and subsequent to construction. Deposition of sediment may be induced by overexcavating a portion of the channel to produce a zone of reduced velocities. For continued effectiveness, arrangements must be made to remove sediment from traps, thus sediment traps are most useful during channel construction when equipment is readily available for maintenance. A final cleanout can be scheduled just prior to project completion. Sediment traps placed just ahead of local drainage inlets may be used to remove sediment and associated nutrients (Walker 1979), but long-term use of sediment traps is less practical because of maintenance requirements.

115. Design criteria for in-channel sediment traps for a low-gradient channel are as follows.* Sediment trap bottom width should be double the channel bottom width. Trap depth should be selected based on an estimate of the sediment input and the desired maintenance interval. Trap volume should be sufficient to provide sediment storage and to reduce velocities sufficiently to induce sedimentation. Plans should include access for cleanout and provisions for disposal of sediment.

Placement of excavated material

116. Placement of excavated material from channel enlargement or alignment can have several adverse environmental impacts. One former conventional practice was clearing disposal areas adjacent to the excavated channel and stacking the excavated material at its angle of repose; the shape of the windrow of material thus created was often too regular

---

* Personal communication from T. D. Prestridge, Soil Conservation Service, Alexandria, La., July 13, 1981, to the author.

to blend visually with the surrounding landscape. In some instances, erosion of excavated material delivered substantial quantities of sediment into the channel. The initial loss of riparian vegetation due to clearing for disposal areas was substantial, but most piles eventually revegetated from natural seed sources. In some cases the windrows of excavated material functioned like levees and reduced flood frequency on adjacent lands over and above the reduction supplied by channel modification. Other former practices for disposition of excavated material include spreading on agricultural land, filling severed meanders, filling adjacent low areas and wetlands, and use as construction fill for roads or other projects (Arthur D. Little, Inc. 1973).

117. Selective placement of excavated material provides opportunities to reduce adverse environmental impacts associated with channel enlargement or alignment. Considerations for the disposition of excavated material include the amount of clearing required for various schemes, landforms and topography adjacent to the channel, existing and projected land use, rare or endangered plant species, location of wetlands, and unique wildlife habitat. The ability of the material to support vegetation determines the need for mulching, fertilization, and plating with topsoil. Placement of excavated material should allow for future project maintenance.

118. Excavated material may be graded to natural contours that blend with surrounding land forms. A gentle, low swell or rise adjacent to the channel can be used to mark the boundary of a riparian buffer strip easement without being visually obtrusive. The low rise can also be abrupt enough to discourage operation of farm equipment within the riparian buffer strip. Excavated material can be used to shape the tops of channel banks to prevent uncontrolled entry of side drainage with attendant erosion of channel side slopes. Grizzell and Vogan (1973) recommend placing excavated material in piles when the project passes through intensively farmed flatland areas. The revegetated piles provide wildlife habitat and a haven from rising floodwaters for terrestrial species. In urban areas excavated material may be used to develop a park-like atmosphere around the channel by constructing noise and

visual barriers to screen views of unrelated activities.

119. Excavated material can be placed intermittently to allow some flooding of adjacent areas, or it can be used to build levees to keep water in low-lying areas adjacent to the channel. McCall and Knox (1978) report the use of such levees to protect a 65-acre tract containing forested wetland adjacent to a flood-control channel. There was a lense of impervious material underlying the wetland that allowed water to be contained perched above the stream elevation. Without the impervious layer, water might have seeped through the channel banks and caused bank failure. Low levees were built on two sides of the tract, and a riprap chute was constructed to allow exchange of water between the protected tract and the channel. The protected tract was purchased as part of the flood-control project.

120. Placement of excavated material should be planned so that material containing pollutants or undesirable naturally occurring constituents is covered by material more appropriate for surface exposure and revegetation. Plans for enlargement of the Castor River in Missouri call for contaminated bottom sediments excavated from the channel bed to be covered by noncontaminated material excavated from the upper bank. The pollutants (pesticides) would thus be safely confined in the excavated material embankment. The embankment would be shaped, fertilized, and seeded promptly to prevent erosion, and sufficient right-of-way would be acquired by the government to prevent degrading any portion of the confinement embankment for any purpose (Memphis District 1979).

Vegetation

121. Many of the adverse impacts of channel work can be avoided or reduced by preservation of existing vegetation and prompt revegetation of bare or denuded areas with appropriate species. The importance of riparian vegetation to aquatic and terrestrial communities, water quality, bank stability, aesthetics, and channel maintenance has been noted above. A primary intention when planning revegetation for flood-control projects should be that the vegetation neither hinder nor negate the flood-control effort. Trails may be constructed for walking, bicycling, or nature study through riparian greenbelts (U. S. Army Engineer

District, Huntington 1980). Recreation facilities associated with flood-control channels are discussed in greater detail below.

122. Money and effort spent on preserving and planting vegetation may be wasted if the vegetated areas are not protected by easement or fee acquisition from grazing, clearing, or cultivation after project completion. Fencing may be necessary to protect vegetation from livestock that are grazing adjacent tracts. When buffer strips are adjacent to cultivated land, permanent markers such as metal posts may be necessary to mark the limits of the easement, particularly while plantings are small (Figure 24). Minimal boundary protection may be provided by

Figure 24. Metal posts used to mark boundary of riparian greenbelt, Buck Creek, Indiana

constructing a low ridge of excavated material at the outer edge of vegetated areas.

123. If significant woody vegetation is present along the existing channel, the modified channel should be aligned to preserve as much vegetation as possible, subject to other constraints. Existing vegetation can be inventoried, and outstanding individual trees assigned a numerical rating based on age, size, habitat value, relative scarcity or

abundance, proximity to residences or bridges, etc. Channel designers can then attempt to plan channel alignment, single-bank modification, access routes, disposal area locations, and structure locations in such a way as to maximize the sum of the values of preserved trees.

124. It should be noted that even if trees are not removed they may be killed or badly damaged by equipment impacting trunks, limbs, and roots; compaction of soil over feeder roots; stockpiling soil and construction material on the root zone; trenching across roots; and by sudden changes in soil moisture conditions (Amimoto 1978). Outstanding trees in fill areas may be preserved by constructing tree wells equipped with drains to release receding floodwaters. Preserved trees should be disease free and structurally sound and able to withstand wind loading under postconstruction conditions. Wind loading is sometimes a concern when a single, shallow-rooted tree from a thick stand is preserved (Animoto 1978).

125. Successful revegatation of denuded project sites requires selection of appropriate plant species and use of proper propagation and maintenance techniques. Species selected should be well adapted to the soils and moisture regime of the site, provide food and cover for wildlife, and add to project aesthetics. In some settings where rainfall is plentiful and there are seed sources available, natural revegetation processes are superior to artifical revegetation, particularly in selection of species tolerant to ambient soil and water conditions. Careful maintenance of these areas through selective elimination of less desirable growth will provide for a more natural appearance. Recreation and wildlife benefits can both result from revegetation that will attract songbirds and other animals to areas that are accessible to the general public (National Wildlife Federation 1974). In general, revegetation schemes should avoid "aboretum-type planting"; i.e., the planting of many different species (OCE 1972), but should include enough species to provide a diverse habitat for wildlife. The Environmental Laboratory (1978) and Hunt et al. (1978) present detailed information on wetland and terrestrial plant selection and propagation, including regional, site condition, and habitat value considerations. Coastal Zone

Resources Division (1978) presents life history and propagation information for 100 plant species with wildlife habitat value. Whitlow and Harris (1979) provide guidance for selection of flood-tolerant plant species. The arrangement of trees, shrubs, and other plants, as well as the species selected for planting, is important to the final appearance of the project. Mann et al. (1975) presents a general introduction to landscape design and tabulates information about hardiness, size, optimum soils, preferred soil moisture, drought tolerance, propagation methods, and nomenclature for several species of trees and shrubs.

126. Without close inspection and enforcement of specifications, the survival rate for planted vegetation may be quite low. One method for ensuring an acceptable survival rate is to include provisions in the landscaping contract for replacement of dead plantings after a certain period of time. This approach may be prohibitively expensive, however, due to the increased risk for the contractor.

127. In some cases revegetation of cleared banks or other denuded areas may be accelerated by transplanting with a tree spade, shrubs, saplings, and even small trees from areas to be cleared. Topsoil may be stripped from construction areas and stockpiled if plating material is needed. Nursery stock may also be used to establish trees and shrubs. Since nursery stock and transplants are perishable, care should be taken to specify and enforce handling and planting methods that maximize survival. It may be necessary to use herbicides in conjunction with planting of seedlings to reduce competition from weeds. Dry-season watering may be required during the first few years of the project in arid and semiarid regions.

128. Revegetation plans should be formulated with consideration of future operation and maintenance requirements. It may be necessary to exclude woody plants from access routes and future disposal areas. However, substantial benefits may be derived from plantings even if they must later be cleared for maintenance if the projected maintenance cycle is extremely long. Maintenance equipment can sometimes reach over low-growing trees and shrubs, or work around well-spaced trees.

Restoration of terrestrial habitat

129. Revegetation of the riparian zone is a key aspect of terrestrial habitat restoration. Diversity of wildlife species is affected by the diversity of food-producing plant species. Other habitat development techniques include structural measures to provide den and nesting sites such as waterfowl nesting boxes and platforms. Some maintenance activities may be scheduled to minimize impacts on wildlife. Mowing, for example, may be delayed to allow ground-nesting birds to reproduce successfully. Additional information is available in Schemnitz (1980), a standard work in this field. Later work under EWQOS Project VI will address terrestrial habitat restoration in greater depth.

Habitat restoration structures

130. An unaltered, natural stream normally has a variety of depths, velocities, substrates, and illumination that provides habitat for a diverse assemblage of aquatic organisms. Gorman and Karr (1978) found fish species diversity directly related to habitat diversity in a number of streams. Channel modification for flood control usually results in more uniform conditions that cause a decline in aquatic species diversity and a reduction in numbers, biomass, and median size of desirable species. White (1973) points out that physical parameters such as channel shape may be as critical as chemical water quality to some fish species. Habitat structures (also called stream improvement devices, artificial instream structures, stream rehabilitation structures, or habitat restoration measures) are simple structures usually made of stone, gabions, or logs used to correct the physical deficiencies of stream reaches in order to develop suitable habitat for desirable aquatic species.

131. For many decades fishery managers have attempted to correct habitat deficiencies and improve gamefish production in natural streams by constructing simple habitat structures. For example, structures were used to scour holes or impound small pools and provide shelter and cover for adult fish, or to create clean gravel riffles for salmonid spawing or invertebrate production.

132. Although some authors question the cost effectiveness of

using habitat structures in unaltered streams as a fishery management tool (Hunt 1971, Calhoun 1966, Mullan 1962), structures have been used successfully in a number of instances to speed the biological recovery of enlarged or relocated streams (Shields and Palermo 1981). Structures have generally had a positive impact on fish populations when properly designed and installed, although they do adversely effect some species while benefiting others (Edwards 1977). In most cases habitat structures placed in modified channels have produced conditions superior to conditions that would exist without habitat structure, but inferior to unaltered conditions (Barton and Winger 1974, Griswold et al. 1978).

Types of habitat structures

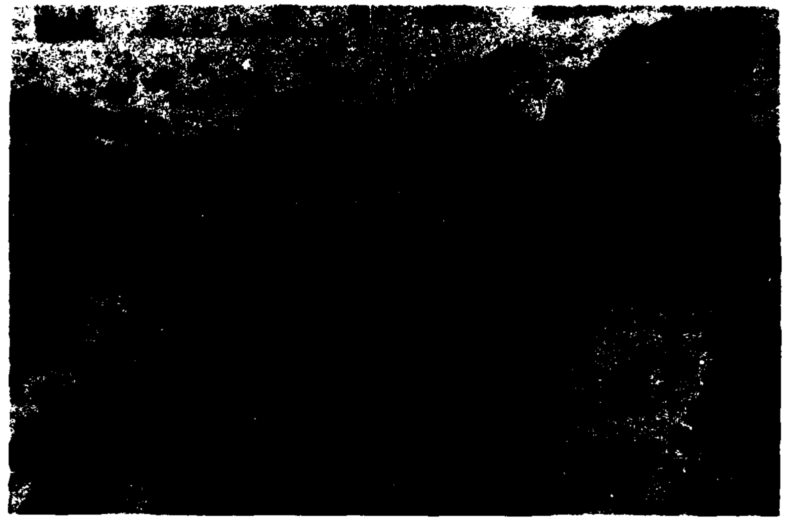
133. Although numerous designs for habitat structures have been used, all structures may be placed in three categories: sills, or low dams; deflectors; and random rocks (Figure 25).*

134. Sills. Sills are low structures which entirely cross the channel, except perhaps for a gap or notch. They are typically quite low and have minimal backwater effect. Sills are usually designed to produce either a small pool upstream, or a downstream scour hole, or both. Sill abutments must be well protected to prevent erosion and flanking, and sills should be keyed in to both bed and banks. The Federal Highway Administration (1979) suggests a minimum key trench depth of twice the height of the sill crest and a minimum bank key-in of 10 ft. Downstream scour holes may be stabilized with riprap or other protective material, and the material scoured from the region below a sill may be deposited a short distance downstream to form a riffle. A broad-crested sill may itself act as a riffle, particularly if it is submerged most of the time (Griswold et al. 1978). Sills may be constructed with sloping crests, notches, or gaps to concentrate low flows in order to maintain scour holes and thus provide greater depths. Notched structures usually require that downstream banks be protected from eddy scour.

---

* The terms "sills," "deflectors," and "random rocks" as used in this report have highly specialized meanings as defined in this section.

a. Rock sill



b. Gabion deflector

c. Random rocks

Figure 25. Habitat restoration structures (Barton and Winger 1973)

135. Deflectors. Deflectors are habitat structures which protrude from one bank but do not extend all the way across the channel. Deflectors may be angled downstream or placed perpendicular to the bank. In plan, deflectors may either be simple jetties, or triangular if protection is desired for the near bank. Deflectors in series are normally installed on alternate banks to produce a meandering thalweg. Deflectors are keyed in to bed and banks in a manner similar to sills. Some deflectors are shaped like an "A" or "V" in plan and do not key into the bank; these are not recommended because of their tendency to clog and cause erosion of both banks (Nelson, Horak, and Olson 1978).

136. Random Rocks. Random rocks are large boulders, gabions, or concrete objects randomly placed or grouped in the channel well away from either bank. Random rocks provide habitat by producing small downstream scour holes and zones of reduced velocity. Rocks will generally not be effective in low-velocity streams (less than 2 to 3 ft/sec) or in streams with fine, noncohesive bed material such as sand or fine gravel. Fine, noncohesive bed material will scour so deeply and rapidly that the rock will be undermined and buried. Random rocks may be placed in deep areas or pools created by sills to provide additional cover. Rocks may be placed in intermittent clusters in very steep channels to create cascades and "stair-step" pools (Federal Highway Administration 1979).

Documented experience

137. Cases where design procedures for and the biological effectiveness of habitat structures for flood-control channels have been documented are rare. Designs typically follow those used earlier in unaltered streams and rely heavily on professional judgement rather than quantitative analysis. Biological studies of modified channels with habitat structures are rarely extensive enough to be conclusive. Shields and Palermo (1981) briefly review five studies of the effectiveness of habitat structures (Barton and Winger 1973, Winger et al. 1976, Griswold et al. 1978, Lund 1967, Witten and Bulkley 1975, McCall and Knox 1978). Habitat structures have been used successfully in a number of instances to speed recovery of popul   s of fish and macroinvertebrates in

modified channels. Additional review of documented experience can be found in Appendix A of this report.

Planning and design of habitat structures

138. Formal design criteria have not been produced for habitat structures. Most existing habitat structures were designed based on general descriptions of stream improvement devices employed in unaltered streams by fishery managers and on the professional judgement of individual designers. Only general qualitative guidelines are presently appropriate because of the current lack of information and the unique characteristics of each situation.

139. A few references are available that discuss planning, design, and construction of habitat structures (Federal Highway Administration 1979, U. S. Department of Agriculture Forest Service 1969, White and Byrnildson 1967, and Barton and Winger 1974), but these generally deal with either small, unaltered streams or streams that are relocated but not enlarged. All of these documents contain qualitative guidelines and basic principles for the use of habitat structures. The Federal Highway Administration (1979) presents an extensive discussion on the use of habitat structures to restore relocated coldwater streams with very coarse bed material. The U. S. Department of Agriculture Forest Service (1969) gives detailed design guidance for improving stream fish habitat; however, this guidance is most appropriate for small streams. White and Byrnildson (1967) discuss the use of structures to improve trout habitat in small Wisconsin streams, and Barton and Winger (1974) present a catalog of many types of stream habitat structures.

140. Feasibility of habitat structures. Habitat structures should be considered only for channels where water quality and quantity are sufficient for a viable fishery. Habitat structures will not be effective in unstable channels that are experiencing rapid aggradation, since sediment deposition can destroy pools and holes created by structures and blanket rocky surfaces important as substrate for macroinvertebrates (Mullan 1962, U. S. Department of Agriculture Forest Service 1969). Channel degradation will undermine structures and cause them to collapse.

Habitat structures are not recommended for channels with gradients greater than 3 percent (Burgduff 1934, Calhoun 1966). Habitat structures need not be considered for channels where habitat diversity, depths, velocities, or substrate are not constraining factors on the desired aquatic community. If enough habitat structures are used to effectively restore the damaged or destroyed habitat, channel roughness may increase enough to require additional flow capacity. In some cases, therefore, the feasibility of slightly increasing flow capacity to allow for the increased roughness will be a factor in determining the feasibility of habitat structures.

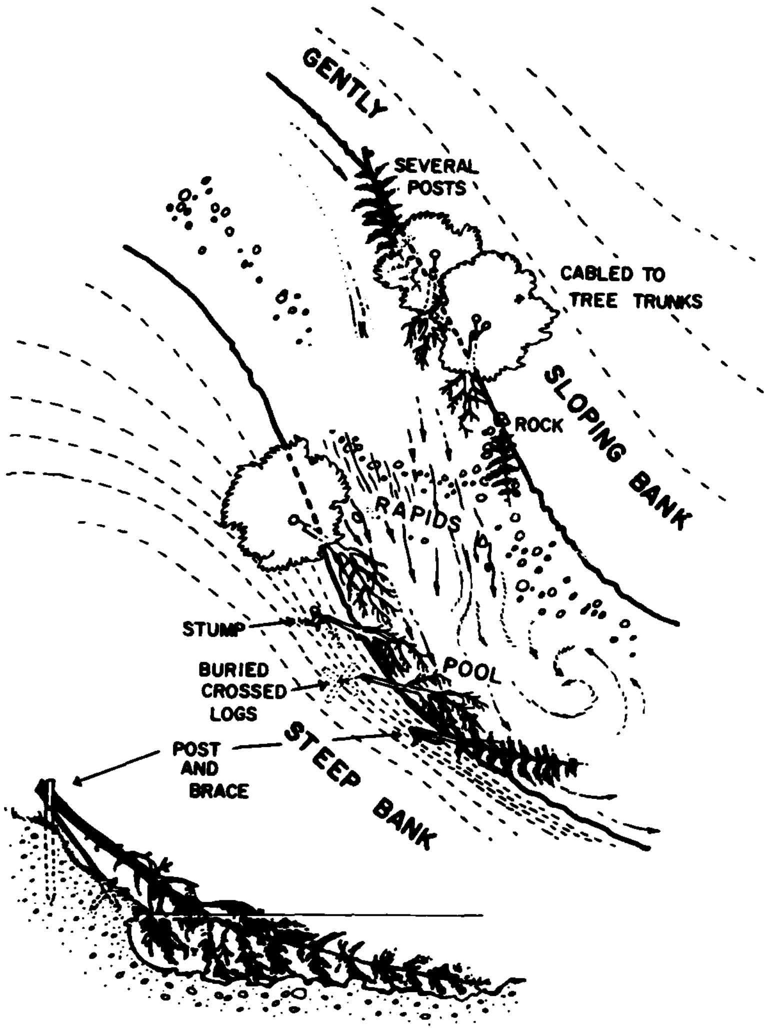
141. Design and construction of any structure within a flood-control channel is a difficult task--whether the structure is for grade control, bed stabilization, water level control, support of a bridge, or improving aquatic habitat. Appropriate measures must be taken to prevent undercutting, flanking, and undesirable bed and bank erosion. Stone structures should be built of stones sufficiently large to withstand the maximum velocities expected to occur in the vicinity of the structure. Structures should be designed to function effectively under expected sediment loading and not interfere with the ability of the channel to transport sediment. Since most modified streams do gradually develop some physical irregularity and experience biological recovery, it is not necessary that habitat structures be designed to last as long as the project itself. Instead, structures may be designed to bridge the gap between the stark conditions of initial completion and biological recovery. Even the rubble or debris from a failed structure can benefit the aquatic community (U. S. Army Engineer District, Seattle 1965).

142. Design procedure. Layout and design of habitat structures should be an iterative process. The following steps are presented as general procedural guidelines:

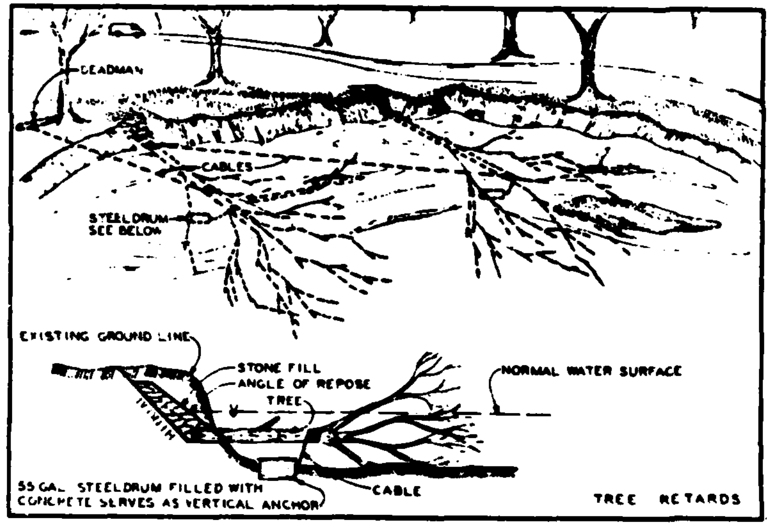
a. Determine habitat deficiencies. The characteristics of the modified channel should be examined in light of the habitat requirements for the desired aquatic community, including requirements for fish spawning and rearing. Habitat structures should be designed to correct deficiencies. Particular attention should be paid to depth and velocity requirements. Alternatively, the habitat structure plan can be based on the characteristics (pools, riffles, cover, shade, substrate) of the unaltered channel. Habitat requirements for spawning may require provision of special depth, velocity, and substrate conditions. Bell (1973) presents design criteria for spawning channels for certain salmonid species. Carline and Klosiewski (1981) suggest preservation of unaltered reaches in large projects or creation of off-channel ponds permanently attached to the channel. Such ponds would be valuable to species such as sunfish, which require little or no current and stable water levels for successful reproduction.

b. Plan layout. The general location of each structure should be determined. This may be done after channel layout to avoid conflicts with crossings, drop structures, etc. Placement of structures in bends may create complicated turbulence patterns and make bank erosion difficult to predict and control. Sills, deflectors, or random rock clusters should be spaced to produce a natural pool-riffle sequence, with pool centers five to seven stream widths apart measured along the channel. The Federal Highway Administration (1979) suggests placing random rocks with a density of one large rock per 300 sq ft. Kanaly (1975) reported a density of one 7-ft-diameter boulder per 750 sq ft provided habitat superior to a density of one per 500 sq ft. Structures should be placed at slightly irregular intervals to produce a more natural appearance. Care should be taken to place structures where they will be in water during low flows. In some cases it may be advantageous both biologically and hydraulically to place structures in the low-flow channel only, and in such a case, provisions should be made to avoid flanking by flows which slightly exceed the low-flow channel capacity.

c. Select the types of structures. The general type of structure to be placed at each selected location should also be determined as part of the layout process. Criteria for selecting the types of habitat structures include the desired physical effect, the velocity regime, bed material, economics, aesthetics, constructability, and availability of materials. In some cases only hiding cover is needed, while other situations call for vertical relief. Felled trees anchored or cabled to deadmen on the bank can provide good hiding cover, although they are not recommended for locations subject to ice attack (Gore and Johnson 1980 and 1981) (Figure 26). Rocks and rock structures also provide a limited amount of hiding



a. Anchoring methods suggested by White and Byrnildson (1967)



b. Tree retards used experimentally for bank protection (OCE 1978)

Figure 26. Use of trees for habitat structures

cover. For vertical relief, structures or boulders must be placed so that there will be sufficient current velocity to scour a small depression in the existing bed material. Structures such as deflectors or boulders are more appropriate for steep, high-velocity channels than structures which completely cross the channel. Smaller stones may be used in gabions, but gabion baskets eventually fail due to corrosion and/or abrasion and jagged wire from failed gabions can be hazardous to recreationists. As noted above, structures placed in channels with fine, noncohesive bed material tend to be undermined by scouring and buried. Random rocks are particularly susceptible to this type of failure since they are not keyed in to the bed or banks. Sheet piling may be used successfully to build sills and deflectors in some channels with fine bed material; however, sheet piling is aesthetically inferior to stone. Bedrock channels may be shaped by blasting and excavation to create holes, pools, and overhanging banks that provide cover, substrate, depths, and velocities suitable for good aquatic habitat. Material removed by blasting may be used to build riffles or to direct flow. Certain types of structures require more hand labor in construction, and this factor should be considered in economic comparisons.

d. Size the structures. Structures should be sized to produce the desired aquatic habitat with minimal effect on the maximum flow capacity. The Federal Highway Administration (1979) contains plan and section drawings for several types of structures, as well as dimensions for sills, deflectors, and random rocks. Habitat structures should be sized and spaced to avoid large areas of uniform conditions. Winger et al. (1976) suggest a minimum spacing of three pool lengths between structures that create pools. White and Byrnildson (1967) recommended a maximum pool length of five stream widths. Structures should be low enough that their effects on the water surface profile will be almost completely drowned out at near-capacity discharges. In general, the lowest point on a sill crest, i.e. the invert of a gap or notch, should be at the same elevation as the upstream channel invert. The maximum height of a sill above the upstream channel invert should be no more than one-third the water depth at full capacity. However, maximum height may be further constrained by the effects of a series of structures on channel flow capacity. Deflectors may be sized based on the size of the desired depositional zone and the acceptability of erosion of the opposite bank. If bank erosion is anticipated opposite a deflector, streambank protection may be used; but the net result will be a narrower and perhaps deeper channel. Random rocks should be sized to withstand maximum velocities but should be no greater in their largest dimension than one-fifth of the channel width at normal flow (Federal Highway Administration 1979). Given the maximum velocity, rocks may be sized based on the curve for an isolated cube in Plate 9 of EM 1110-2-1601 (OCE 1970), or using rules of thumb given by Federal Highway Administration (1979). Structures that are too high or too close to an upstream structure may pond water all the way back to the previous structure, leaving no space for a riffle to develop between them. Other problems caused by improperly sized structures include premature failure, blockage of fish migration, streambank erosion, and flanking.

e. Investigate hydraulic effects. The effects of habitat structure on both high and normal flows should be investigated. Effects at high flows are of interest because of the possible impact of structures on flow capacity. Hydraulic conditions at normal and low flows should provide favorable aquatic habitat. Structures should not produce velocities or drops that are barriers to migration. Hydraulic effects of structures are best investigated using physical models. Numerical models may be used for less exact estimates by treating structures as roughness elements, low weirs, or contractions. The effect of a long series of structures on maximum flow capacity can be approximated by increasing the coefficient for roughness or resistance in a uniform flow equation, but the amount of increase is usually a matter of judgement. The Federal Highway Administration (1979) presents a method for increasing the channel roughness coefficient to account for random rocks installed as habitat structures.

f. Consider effects on sediment transport. Habitat structures will modify the patterns of scour and deposition in a channel, but the precise nature of the effect is difficult to predict. Experience and observation of existing installations are probably the most practical tools available to flood-control channel designers for estimating the effects of habitat structures on sediment transport. Before designing structures for erodible channels, it may be wise to allow the modified channel to "season" through several high-flow events. Properly sized structures should not significantly reduce the ability of the channel to transport sediment. However, as discussed above, channel instability and sediment deposition can negate the effects of structures.

g. Select materials for construction. Materials used for habitat structures include riprap, logs, timber, boulders, stone, gabions, concrete, and felled trees. In some cases it may be feasible to salvage large logs, boulders, or rock from clearing and channel excavation for habitat structures. Log structures give long service if continuously submerged and are more natural looking than gabions or concrete. Alternately wet and dry logs can give up to 20 years of service, and treated logs and timber give even longer service (Federal Highway Administration 1979). Concrete structures may be an alternative to gabions or rock in some situations. Concrete may be formed into a number of different shapes (Barton and Winger 1974).

h. Ensure structural stability. Habitat structures should be designed to withstand maximum velocities and turbulence expected to occur in the vicinity of the structure. Debris and ice loads may warrant even more durable design than velocity considerations. A range of discharges should be considered since critical flow over or around a habitat structure may occur at a discharge considerably smaller than the design event. Generally, notches in sills and the riverside tips of deflectors are subject to highest velocities. Banks should be well protected in regions of anticipated scour both upstream and downstream of a structure. Such bank protection can itself be a positive influence on the aquatic habitat (Winger et al. 1976). Structures should be keyed in to bed and banks to prevent undermining and flanking. Gravel bedding or filter cloth may be used underneath stone in key trenches to prevent washout of fines.

i. Supervise construction. Construction of habitat structures and other environmental features must be closely supervised to ensure desired effects are achieved and initial disturbance is minimized. Plans and specifications for habitat structures should allow a team consisting of a fishery biologist and a hydraulic engineer to make minor adjustments in structure placement and design during construction. Remnants of existing habitat may be preserved, and adjustments can be made to allow for unforseen contingencies.

j. Follow up. Habitat structure installation should be followed by regular monitoring, adjustments, and maintenance. A followup program is important with flexible construction materials like rock, because minor changes can halt incipient problems and produce the originally desired effect. In some cases design uncertainties can be compensated for by followup work, but additional funds must be allocated and some uncertainty accepted in cost estimates. Monitoring and adjustment allows designers to learn from past actions and develop skill for future work.

Substrate construction

143. The bed material in an unaltered natural stream is usually well sorted, with a thin armor layer of coarse material overlying a layer of material with a wider size gradation. Bed material in riffles is coarser than in pools. The native aquatic community, particularly the benthic community, is adapted to the existing bed material or substrate. Channel modification usually results in poorly sorted, finer, and less stable bed material, and the recovery of the armor layer may be quite slow. Arner et al. (1976) reported that the finer, poorly sorted bed materials in both a recently modified segment of the Luxapalila River, Mississippi, and a segment modified some 52 years before resulted in plankton and macroinvertebrate communities which were inferior in both quality and quantity to those found in an unaltered segment.

144. One approach to speeding recovery of channel substrate and populations of dependent aquatic organisms is to line the modified channel with a biologically desirable bed material. However, the expense of lining a channel with rock or stone that will be relatively stable in modified channel velocities may be prohibitive. The biological benefits of the substrate will be minimal if the layer of material is blanketed by sediment deposition. On the other hand, such lining might stabilize an irregular channel bottom topography and generally contribute to overall channel stability.

145. Gore and Johnson (1980 and 1981) discuss the biological recovery of a stream relocated (but not enlarged) to allow for coal mining operations. Excavated material available from the mining operation was used to line the new channel with relatively uniform layers of topsoil, gravel, and small to medium cobble (1 to 6 in. in diameter). This substrate size was selected based on observation of undisturbed areas of the same stream. The highest diversity of aquatic insects was found in shallow, high-velocity riffles with this size substrate. Macroinvertebrate populations were rapidly established in the relocated channel by colonization from adjacent undisturbed reaches.

146. The U. S. Soil Conservation Service constructed an enlarged flood-control channel for Prairie Creek in Indiana armored with a 0.5-ft

lining of No. 2 coarse aggregate (1- to 2-in.-diameter river gravel). The armor was included mainly for stability; any biological or aesthetic benefits were incidental to its main purpose. Additional data about this project can be found in Appendix A.

Lined Channels

147. Channel lining or paving normally creates an extremely unnatural channel bed, in addition to all of the impacts associated with channel enlargement and alignment, and thus has quite severe environmental impact. The artificial appearance tends to be visually displeasing to most observers. Channel lining has been observed to promote higher water temperatures; algal growths; wide, shallow flows; excessively high velocities; and decline and/or loss of native fauna (Shields and Palermo 1981). Concrete-lined channels are usually used only in highly congested urban areas. Typically, aesthetic impacts would be more important in such a setting than impacts on aquatic habitat.

148. Measures to alleviate the adverse impacts of lined channels include those discussed above for water level control, placement of excavated material, and preservation and planting of vegetation. Thermal effects of the lining make shade especially desirable. A curving alignment can improve the aesthetics of a lined channel, and impoundment of water in the channel during normal flows using an inflatable or removable structure (as described above) can improve project aesthetics and provide some recreation and fishery benefits.

149. The impact of lined channels on the aquatic community may be alleviated by attempting to create more natural substrates and hydraulic conditions. Alternatives to conventional types of paving that provide somewhat more natural conditions include boulder concrete (U. S. Army Engineer District, Honolulu 1975) and riprap, with stream gravel placed on the riprap to fill voids (U. S. Army Engineer District, San Francisco 1980). These linings will not provide habitat for the same benthic community an unaltered stream does, but they do provide more valuable habitat than ordinary concrete. Economic considerations

tend to mitigate against extensive use of measures that create more natural hydraulic conditions since the cost of lined channels is justified by their hydraulic efficiency.

150. Since lined channels usually produce higher velocities and shallower depths than natural channels, impacts on fish habitat can sometimes be addressed by using low-flow channels, resting pools, fishways, and spawning channels. Low-flow channels may be constructed in the bottom of a lined channel to concentrate normal flows and produce greater depths and should be aligned close to the bank of the larger channel to take advantage of existing and future shade. Pools may be placed in the low-flow channel at appropriate intervals to allow resting stations for fish migrating upstream and to provide a more natural channel geometry. Intervals and dimensions for resting pools should be based on the requirements of the fish species desired for the completed channel. A baffle or notched weir placed just upstream of a resting pool concentrates low flows for more satisfactory water depth and promotes self-cleaning (San Francisco District 1980).

151. Fishways, i.e. narrow, baffled channels, may be used to provide passage for migratory fish around obstructions such as drop structures, culverts, or unusually steep reaches of channel. Fishways should be designed to provide passage over a wide range of flows and have a resting area at the downstream end. Additional information about the design of fishways is found in Bell (1973). Watts (1974) and McClellan (1970) discuss the design of fishways for culverts.

152. Loss of spawning habitat due to construction of a lined channel may sometimes be partially compensated for by providing access to unaltered spawning areas in upstream reaches or tributaries. Alternatively, artificial spawning habitat may be provided by constructing a spawning channel parallel to the main channel. The spawning channel should have appropriate depths, velocities, and substrates to meet the requirements of the species in question. Periodic replenishment of the substrate in the spawning channel may be necessary. Transport of material out of the spawning channel may be reduced by constructing sills of concrete or gabions at intervals across the channel (San Francisco

District 1980). If spawning facilities are included in a channel project, suitable rearing habitat must also be available. Design criteria for spawning channels for salmonids have been reported by Bell (1973).

153. Cover and shelter for fish and habitat for some invertebrates in a lined channel may be increased by anchoring boulders or stumps in pools. Hardwood stumps should be inverted, angled downstream, and well anchored below the water surface to reduce the rate of decay (San Francisco District 1980). Cover and shelter should not be provided if depths, velocities, or water quality are not suitable for fish.

Special Considerations for Urban Projects

154. Stream channels often pass through urban areas in relatively undeveloped corridors. Modification of such channels for flood control offers many opportunities for recreational development and beautification, and these features are frequently easier to include in an urban project because the higher levels of project usage make these measures more attractive to local sponsors.

155. An extremely wide floodway adjacent to urban development can be used for a golf course, a fishing lake, shooting ranges, minibike courses, and athletic playing fields. With proper zoning to control land use within the floodway, a multiple-use greenbelt park can be developed. Lighting, parking, water supply, picnic tables, fireplaces, sanitation facilities, and other amenities may be added based on projected use and available funds. Amphitheaters or exhibit areas may be appropriate for downstream areas. Special plantings and a meandering low-flow channel can complete the park-like atmosphere (Detroit District 1974; U. S. Army Engineer District, Los Angeles 1973; Marvin Springer and Associates 1973).

156. Even a relatively narrow flood control project may be designed to include trails. Trails or walkways adjacent to a channel through an urban area hold many possibilities for day use recreation (Figure 27) and can connect the distant units of an urban park system by means of an undeveloped greenbelt. Unless trails and walkways are part

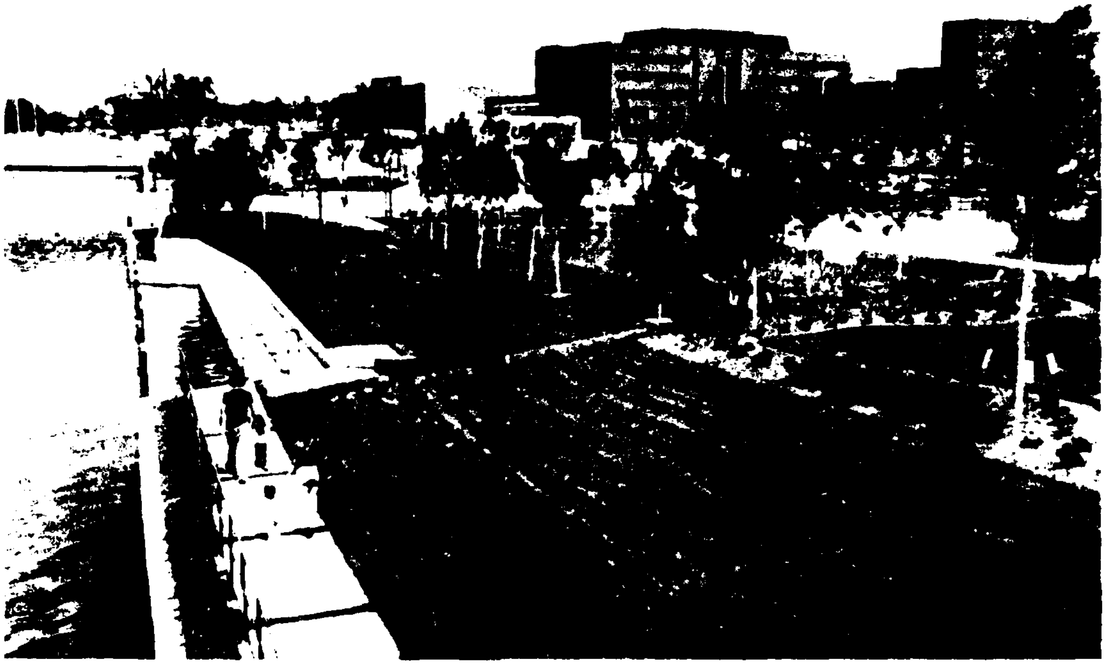


Figure 27. Walkway and landscaped berm adjacent to urban flood-control channel. Water level in the channel is maintained by an inflatable dam, Flint River Flood-Control/Beautification Project, Flint, Michigan

of a waterfront-type development, they should be separated and screened from normal traffic. Unpaved trails constructed along levee crests or on benches in channel sideslopes or levee embankments can be used by equestrians, joggers, or hikers. Hitching posts may be provided along equestrian trails. Paved trails can be used by bicyclists as well as pedestrians if proper line of sight and head clearance is provided. Paved trails may also be constructed with gentle enough grades for wheelchair use. However, if simultaneous trail use by more than one type of traffic is permitted, trail design should incorporate sufficient traffic controls and safety features to avoid hazards. Trails should pass under major street crossings if there is sufficient clearance. Trail bridges across the channel and occasional approaches to the water's edge add variety to the trail experience, as do curving alignments, interpretive markers, display cases, benches, and ornamental vegetation. Trail heads should be clearly marked, and public parking should be provided nearby if the trail head is not within easy walking distance of most potential users. It may be desirable to place motorcycle and automobile barriers at trail heads to exclude these types of vehicles from the trail system (Marvin Springer and Associates 1973, U. S. Army Engineer District, Tulsa 1976, U. S. Army Engineer District Omaha 1977, Mertes et al. 1972).

157. A relatively undisturbed area within the project can accommodate an unobtrusive nature trail. Various plant species may be marked and viewing blinds provided for study and photography of birds and other wildlife. Larger areas may be dedicated to displays of wildflowers or other unique vegetation (Marvin Springer and Associates 1973, U. S. Army Engineer District, Fort Worth 1979). A useful reference for wildlife-related features in this setting is Leedy, Maestro, and Franklin 1978).

158. Inclusion of features for water-based recreation in urban flood-control channel projects should be contingent upon projected (not existing) water quality and quantity conditions in the completed project. Some flood-control channels can be constructed to provide opportunities for boating, canoeing, or fishing, but water quality in urban channels is usually not sufficient for water contact activities such as swimming. Low-flow channels may be designed to provide depths adequate for boating or canoeing. Alternatively, water may be impounded in the flood-control channel by an inflatable dam (see paragraph 106) to provide depths sufficient for boating (Figure 28). Variations in channel width and slope will create variations in current velocity, and gabions or large boulders may be used to create easy "rapids." Drop structures and utility crossings should be equipped with chutes to pass boats if practical. If chutes cannot be provided, then warning signs and portage paths should be placed to allow unbroken use of the boating reach.

159. Fishing in an urban flood-control channel can be popular due to its easy access. A viable fishery is a prerequisite for fishing, and suitable water quality, depths, velocities, and habitat structure must be available. Fishermen can utilize access roads, pedestrian bridges (or abandoned vehicle bridges), the tops of certain habitat structures, or specially constructed fishing platforms.

160. Project aesthetics are particularly important for a

Figure 28. Canoeing in recreation channel adjacent to urban flood-control channel, Flint River Flood-Control/Beautification Project, Flint, Michigan

high-visibility urban stream, and pleasant views are prerequisite for most recreational activities. If the existing stream is visually degraded, the flood-control channel project will offer the opportunity to substantially improve existing conditions. High-visibility areas should be designed by landscape architects to harmonize with surrounding views and provide a pleasant visual experience consistent with the expected uses of the area. Landscaping and landscape architecture for confined dredged material sites are discussed by Mann et al. (1975), and some of this information is transferrable to flood-control channels.

161. Concrete structures such as floodwalls, drop structures, bike trails, sidewalks, and benches may be colored, textured, or veneered with stone or gravel to give them a more natural appearance. Other structures, such as utility outfalls, light posts, and habitat structures, should be constructed of materials that blend unobtrusively with the surroundings. Riprap bank protection may be covered with

topsoil (stockpiled from stripping operations or imported) and planted.

162. Planting and preservation of vegetation is important to project aesthetics. Significant trees in fill areas may be preserved by constructing tree wells equipped with drains to release receeding floodwaters. Ornamental plantings should offer a variety of colors and textures. Consideration should be given to allowing natural vegetation to grow two to three feet high in floodways (Los Angeles District 1973), or allowing occasional large trees to border the low-flow channel as in Figure 29 (Kansas City District 1972). Additional information about vegetation is presented above in paragraphs 121-129.

163. As an aesthetic feature, water may be withdrawn from the flood-control channel and allowed to flow through a series of "water displays." Water displays may be flumes, pools, cascades, or fountains (Figure 30). These fountain-like structures can be used as focal points for a waterfront park area (Detroit District 1974).

164. Disadvantages of including recreation and beautification features in urban flood-control channel projects include increased costs for project operation, maintenance, and crime prevention. Park areas adjacent to flood-control channels or within floodways will require a major cleanup effort after floods to remove drift, debris, and sediment. Some structures, such as benches, trash receptacles, light poles, and picnic tables, may be removed from the floodway prior to anticipated high flows to reduce damage and debris accumulation (Detroit District 1974). Additional increased maintenance costs will arise due to vandalism of recreation and beautification features. Constant surveillance may be required in high-density areas, both to protect public property and to prevent other types of crime.

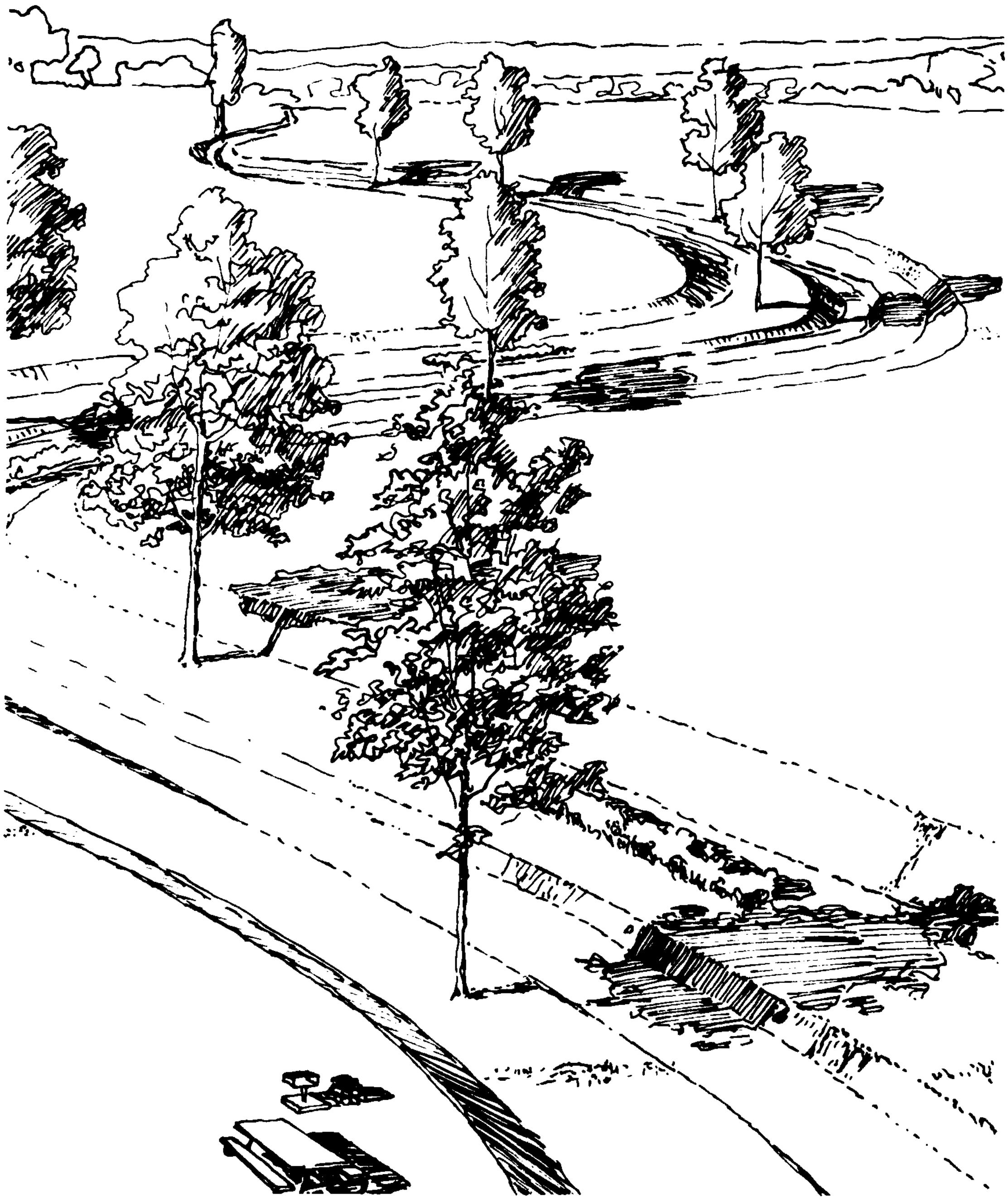
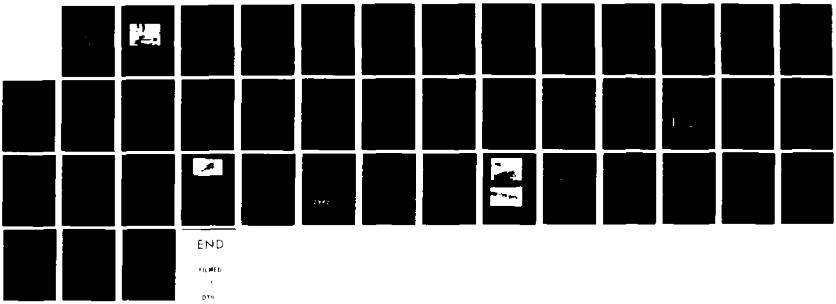
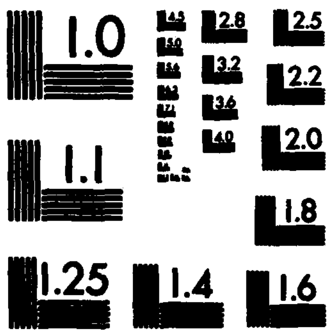


Figure 29. Occasional trees adjacent to low-flow channel in a semi-urban floodway (Kansas City District 1972)

AD-A120 544 ENVIRONMENTAL FEATURES FOR FLOOD-CONTROL CHANNELS(U) 2/2
ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS
ENVIRONMENTAL LAB F D SHIELDS JUL 82 WES/TR/E-82-7

UNCLASSIFIED F/G 13/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Figure 30. Water displays provide scenic amenity for urban flood-control channel, Flint River Flood-Control/Beautification Project, Flint, Michigan

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

165. Flood-control channel modifications are frequently accompanied by severe impacts on aesthetic resources, water quality, fish and wildlife resources, and cultural resources. Reduction or elimination of these impacts will be difficult and costly in many cases; in some cases it will be impossible. The task of producing a flood-control channel project with minimal environmental impact is significantly easier if environmental quality considerations are a key part of the planning and design process from the inception of the project. In fact, there is a noticeable trend toward improvement in the environmental quality of the typical channel project over the last decade since environmental legislation and awareness have begun to affect projects earlier in the planning and design process.

166. Flood-control channel projects should be planned and designed with full consideration of the ecological resources of the project area. Successful incorporation of environmental considerations and attainment of environmental quality objectives require communication and interaction among professionals trained in engineering, life sciences, and other disciplines. A negative attitude toward unorthodox propositions for environmental features is detrimental to a successful design process. Innovative design teams will be able to transform environmental concepts into workable project features.

167. Environmental objectives are usually best attained when channel layout, design, and construction are carried out with meticulous attention to the details of the existing site. Rare or exceptionally large trees and unique geological features can sometimes be preserved by making the design process a procedure of tailoring the project to the site, rather than a gross, general analysis of structural, geotechnical, and hydraulic considerations only.

168. The diversity of stream characteristics found within the United States makes generalizations about streams difficult, if not

impossible. Accordingly, literature dealing with streams must be read with regional climatic regimes, hydrology, geology, and biology in mind. At present, it appears that the greatest amount of information is available on reducing the adverse environmental impacts of coldwater stream modification with coarse bed material.

169. Modification of stream channels for flood control sometimes results in severe channel instability despite the efforts of channel designers to produce a stable channel. Channel instability has severe impacts on water quality, aesthetics, and aquatic habitat, so uncertainties regarding fluvial response to modification are also uncertainties regarding environmental impacts. Careful investigation of the stream's present and past regimes can help the design team estimate the likely response of the stream to channel modification. Full recognition of existing stability problems is necessary to prevent serious instability problems after project construction. In general, channel straightening should be minimized and the existing alignment maintained. The channel cross section should be designed for low flows as well as high flows. The existing velocity-versus-discharge relationship should be preserved as much as is practical at low and intermediate flows to maintain the sediment transport characteristics of the existing channel. A low-flow channel is often useful in this regard. Bank stabilization is usually not possible if the channel bed is unstable.

170. Implementation of environmental measures frequently requires closer supervision and inspection of construction than do other features since many environmental features are unconventional and contractors may be unaware of or unfamiliar with their significance. Awareness of project environmental objectives should continue into project operation and maintenance. Environmental features sometimes necessitate additional or unusual expenditures for maintenance. The modified channel and asso-ciated riparian areas should be protected from further impact due to additional clearing and modification by riparian landowners after construction.

171. Environmental features for flood-control channels are normally aimed at preservation of unaltered zones or reaches, control of

erosion and sediment deposition, preservation or reestablishment of riparian vegetation, creation of irregularities in the stream channel for aquatic habitat, replacement of physical and visual diversity, and improving access to the channel for recreation. Many environmental features reduce the hydraulic efficiency of the modified channel and necessitate trade-offs between environmental and flood-control objectives.

172. Selective clearing and snagging offers an alternative to conventional clearing and snagging but does not significantly increase channel flow capacity. The George Palmiter selective clearing and snagging techniques can be employed to reduce acute local flooding due to channel obstruction, reduce some types of bank erosion, and reduce the environmental impacts of some channel maintenance.

173. Alternatives for channel enlargement and alignment that interfere with the existing channel the least are generally best from an environmental standpoint. Single-bank modification coupled with the use of the natural channel as a low-flow channel within a larger floodway is a viable alternative in some situations. Construction of a meandering low-flow channel with pools and riffles or deeps and shallows can be another approach, but there is little documented experience for designing stable meanders and pool-riffle systems. Water level control structures have been successfully employed to reduce impacts on enlarged low-gradient streams. Sheet-piling weirs have been used on some Louisiana streams, while an inflatable dam has successfully reduced aesthetic impacts in an urban lined channel.

174. Severed meanders may be blocked to form small impoundments. Frequently, however, the flushing rate is so low that stagnation and water quality degradation result. Other oxbow impoundments suffer problems from sediment deposition or dewatering. Even if an oxbow impoundment provides only minimal aquatic habitat, the parcel of land enclosed by the severed meander and the new channel can provide wildlife habitat and visual diversity if it is protected and properly managed.

175. Habitat restoration structures are simple, and literature is available containing qualitative information. However, most of the existing information deals with the use of habitat structures in

unenlarged streams with coarse bed material. Design of habitat structures for flood-control channels should include adequate provisions for structural and channel stability. Structures should be designed to produce depths and velocities suitable for the desired aquatic species at low and normal flows, yet not seriously interfere with the ability of the channel to transport water and sediment during high flows. Habitat structures need not be designed for as long a lifetime as the channel since some habitat recovery will occur naturally. Detailed design of habitat structures may require physical modeling in some cases.

176. Urban flood-control channel projects offer special opportunities for inclusion of aesthetic and recreational features due to their high visibility and proximity to potential users. Such developments normally require a higher level of maintenance and surveillance than an ordinary project.

Recommendations

177. Planning, design, construction, operation, and maintenance of flood-control channel projects should be done in such a way as to maintain or improve environmental quality. Specific methods and techniques to reduce the environmental impacts of channel modifications have been developed and implemented by individual design teams with varying degrees of success. Transfer of experience from one project to another is complicated by the unique physical characteristics of each site, varying project objectives, and institutional constraints.

178. Design of channel modifications should include meticulous attention to detail in an effort to preserve features unique to the site and enhance the environmental quality of the completed project. Especially great care should be exercised to avoid serious instability because of its effects on water quality, aesthetics, and ecological resources. When environmental features are included in a project, construction, operations, and maintenance personnel should be briefed on these features and corresponding recommended procedures. Environmental objectives should also be incorporated into the operation and maintenance manual.

179. Future work under EWQOS Project VI should include further development of design criteria for environmental features such as low-flow channels, floodways, artificial meanders, channels with natural bottom topography, oxbow lakes made from severed meanders, habitat restoration structures, and artificial substrate. Design criteria are needed to produce environmental features that are effective in reducing impacts, durable under conditions found in flood-control channels, and reasonably economical. Existing sources of information and ongoing research should be identified in the areas of aesthetic treatments, recreational features, revegetation, stable channel design, and placement of excavated material. More information is needed on the hydraulic effects and costs of environmental features to facilitate intelligent trade-offs. Methods for estimating the hdyraulic effects, environmental quality benefits, and costs of environmental features should be devised or identified to allow quantitative comparisons of alternatives. Future work should include investigation of techniques for incorporating the hydraulic effects of environmental features in existing CE channel design procedures. Environmental guidance for flood-control channels should be arranged to provide specific guidelines for various regions and types of streams.

REFERENCES

Ables, J. H., and Boyd, M. B. 1969. "Low-Water Weirs on Boeuf and Tensas Rivers, Bayou Macon, and Big and Colewa Creeks, Arkansas and Louisiana; Hydraulic Model Investigation," Technical Report H-69-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Allen, H. H. 1979. "The Role of Wetland Plants in Erosion Control of Riparian Shorelines," Paper presented for the American Water Resources Association at a National Symposium on Wetlands, November 7-9, 1978, Lake Buena Vista, Fla.

Animoto, P. Y. 1978. "Erosion and Sediment Control Handbook," Report No. EPA 440/3-78-003, California Department of Conservation, Division of Mines and Geology, Sacramento, Calif.

Arner, D. H., et al. 1976. "Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water Quality, and Furbearers," Report No. FWS/OBS-76/08, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Arthur D. Little, Inc. 1973. Report on Channel Modifications. U. S. Government Printing Office, Washington, D. C.

Barclay, J. S. 1980. "Impact of Stream Alteration on Riparian Communities in Southcentral Oklahoma," Report No. FWS/OBS-80/14, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Barton, J. R., and Winger, P. V. 1973. "A Study of the Channelization of the Weber River, Summit County, Utah," Utah Division of Wildlife Resources and Utah State Department of Highways, Utah.

Barton, J. R., and Winger, P. V. 1974. "Stream Rehabilitation Concepts," Research Report submitted to Utah State Department of Highways, Utah.

Barton, J. R., et al. 1971. "The Effects of Highway Construction on the Hydrology and Hydrobiology of the Weber River near Henefer," Final Report to Utah Division of Fish and Game and Utah Department of Highways, College of Physical and Engineering Sciences, Brigham Young University, Provo, Utah.

Bell, M. C. 1973. "Fisheries Handbook of Engineering Requirements and Biological Criteria," Fisheries-Engineering Research Program, U. S. Army Corps of Engineers, North Pacific Division, Portland, Oreg.

Brinson, M. M., et al. 1981. "Riparian Ecosystems: Their Ecology and Status," Report No. FWS/OBS-81/17, U. S. Fish and Wildlife Service, Washington, D. C.

Bulkley, R. V., et al. 1976. "Warmwater Stream Alteration in Iowa: Extent, Effects on Habitat, Fish and Fish-Food, and Evaluation of Stream Improvement Structures (Summary Report)," Report No. FWS/OBS-76/16, Biological Services Program, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Burgduff, A. E. 1934. "Stream Improvement," California Fish and Game, Vol 20, No. 2, pp 113-118.

Calhoun, A. 1966. Inland Fisheries Management. State of California Resources Agency, Department of Fish and Game, Sacramento, Calif.

Carline, R. F., and Klosiewski, S. P. 1981. "Responses of Macroinvertebrates and Fish Populations to Channelization and Mitigation Structures in Chippewa Creek and River Styx, Ohio," Ohio State University Research Foundation, Columbus, Ohio.

Chow, V. T. 1959. Open Channel Hydraulics, McGraw-Hill, New York, N. Y.

Coastal Zone Resources Division, Ocean Data Systems, Inc. 1978. "Handbook for Terrestrial Wildlife Habitat Development on Dredged Material," Technical Report D-78-37, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Corning, R. V. 1975. "Channelization: Shortcut to Nowhere," Virginia Wildlife, pp 6-8.

Cummins, K. W. 1974. "Structure and Function of Stream Ecosystems," Bioscience, Vol 24, pp 631-641.

Dale, E. E. 1975. "Environmental Evaluation Report on Various Completed Channel Improvement Projects in Eastern Arkansas," Publication No. 30, Water Resources Research Center, University of Arkansas, Fayetteville, Ark.

Darnell, R. M., et al. 1976. "Impacts of Construction Activities in the Wetlands of the United States," Report No. EPA-60013-76-045, Office of Research and Development, U. S. Environmental Protection Agency, Corvallis, Oreg.

Department of the Army, Office, Chief of Engineers. 1967. "Consideration of Aesthetic Values in Water Resources Development," Engineer Regulation 1165-2-2, Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1970. "Hydraulic Design of Flood Control Channels," Engineer Manual 1110-2-1601, Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1971. "Environmental Quality in the Design of Civil Works Projects," Engineer Manual 1110-2-38, Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1972. "Landscape Planting at Floodwalls, Levees, and Embankment Dams," Engineer Manual 1110-2-301, Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1976. "Environmental Policies, Objectives, and Guidelines for the Civil Works Program of the Corps of Engineers," Engineer Pamphlet 1165-2-501, Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1978. "Interim Report to Congress, Section 32 Program, Streambank Erosion Control

Evaluation and Demonstration Act of 1974," Washington, D. C.

Department of the Army, Office, Chief of Engineers. 1982. "Final Report to Congress, The Streambank Erosion Control Evaluation and Demonstration Act of 1974," Washington, D. C.

Dodge, W. E., et al. 1976. "Channelization Assessment White River, Vermont, Remote Sensing, Benthos, and Wildlife," Report No. FWS/OBS-76/7, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Edwards, C. J. 1977. "The Effects of Channelization and Mitigation on the Fish Community and Population Structure in the Olentangy River, Ohio," Ph. D. dissertation, Ohio State University, Columbus, Ohio.

Emerson, J. W. 1971. "Channelization: A Case Study," Science, Vol 173, pp 325-326.

Environmental Laboratory. 1978. "Wetland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-16, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Federal Highway Administration. 1979. "Restoration of Fish Habitat in Relocated Streams," Report No. FHWA-IP-79-3, U. S. Government Printing Office, Washington, D. C.

Funk, J. L. 1973. "Characteristics of Channels for Warmwater Fisheries," Wildlife and Water Management: Striking a Balance, Soil Conservation Society of America, Ankeny, Iowa.

Gammon, J. R., and Mays, C. E. 1981. "Stream Morphology, Habitat, and Streambank Vegetational Patterns," in Insights Into Water Quality, Indiana Heartland Model Implementation Project Status Report, Indiana Heartland Coordinating Commission, Indianapolis, Ind.

Gore, J. A., and Johnson, L. S. 1980. "Establishment of Biotic and Hydrologic Stability in a Reclaimed Coal Strip Mined River Channel," Institute of Energy and Environment, University of Wyoming, Laramie, Wyo.

Gore, J. A., and Johnson, L. S. 1981. "Strip Mined River Restoration," Water Spectrum, Winter 1981, pp 31-38.

Gorman, O. T., and Karr, J. R. 1978. "Habitat Structure and Stream Fish Communities," Ecology, Vol 59, No. 3, pp 506-515.

Gregory, K. J., and Walling, D. E. 1973. Drainage Basin Form and Process: A Geomorphological Approach, John Wiley and Sons, New York, N. Y.

Griswold, B. L., et al. 1978. "Some Effects of Stream Channelization on Fish Populations, Macroinvertebrates, and Fishing in Ohio and Indiana," Report No. FWS/OBS-77/46, Biological Services Program, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Grizzell, R. A., and Vogan, R. G. 1973. "Characteristics of Channels: Managing Rights-of-Way for Wildlife and Aesthetics," Wildlife and Water Management: Striking a Balance, Soil Conservation Society of America, Ankeny, Iowa.

Headrick, M. R. 1976. "Effects of Stream Channelization on Fish Populations in the Buena Vista Marsh, Portage County, Wisconsin," Report No. FWS/OBS-76/24, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Henderson, F. M. 1966. Open Channel Flow, Macmillan, New York, N. Y.

Herbkersman, C. N. Undated. "A Guide to the George Palmiter River Restoration Techniques," Institute of Environmental Sciences, Miami University, Oxford, Ohio.

Huish, M. T., and Pardue, G. B. 1978. "Ecological Studies of One Channelized and Two Unchannelized Wooded Coastal Swamp Streams in North Carolina," Report No. FWS/OBS-78/85, Office of Biological Services, Department of the Interior, Washington, D. C.

Hunt. L. J., et al. 1978. "Upland Habitat Development with Dredged Material: Engineering and Plant Propagation," Technical Report DS-78-17, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Hunt, R. L. 1971. "Responses of a Brook Trout Population to Habitat Development in Lawrence Creek," Technical Bulletin No. 48, State of Wisconsin Department of Natural Resources, Madison, Wis.

Hunt, W. A., and Graham, R. O. 1975. "Evaluation of Channel Changes for Fish Habitat," Meeting Preprint 2535, American Society of Civil Engineers National Convention, November 3-7, 1975, Denver, Colo.

Hynes, H. B. N. 1970. The Ecology of Running Water. University of Toronto Press, Toronto, Canada.

Johnson, R. R., and Jones, D. A. 1977. "Importance, Preservation, and Management of Riparian Habitat: A Symposium," USDA Forest Service General Technical Report No. RM-43, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Johnson, R. R., Haight, L. T., and Simpson, J. M. 1977. "Endangered Species vs Endangered Habitats: A Concept," in Importance, Preservation and Management of Riparian Habitat: A Symposium, USDA Forest Service General Technical Report No. RM-93, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., pp 68-79.

Kanaly, J. 1975. "Stream Improvement Evaluation in the Rock Creek Fishway, Carbon County (Addendum)," Administrative Report for Project 5075-08-66-02, Wyoming Game and Fish Department, Fish Division, Cheyenne, Wyo.

Karr, J. R., and Schlosser, I. J. 1977. "Impact of Nearstream Vegetation and Stream Morphology on Water Quality and Stream Biota," Report No. EPA 600/3-77-097, Office of Research and Development, U. S. Environmental Protection Agency, Athens, Ga.

Karr, J. R., Toth, L. A., and Garman, G. O. 1981. "Habitat Preservation for Midwest Stream Fishes: Principles and Guidelines," Draft Report, Contract No. 807677, Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, Corvallis, Oreg.

Keeley, J. W., et al. 1978. "Reservoirs and Waterways; Identification and Assessment of Environmental Quality Problems and Research Program Development," Technical Report No. E-78-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Keller, E. A. 1975. "Channelization: A Search for a Better Way," Geology, Vol 3, No. 5, pp 246-248.

Keller, E. A. 1978. "Pools, Riffles, and Channelization," Environmental Geology, Vol 2, No. 2, pp 119-127.

Keown, M. P. 1981. "Field Inspection of the Fisher River Channel Realignment Project Near Libby, Montana," Inspection Report 11, Section 32 Program, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Keown, M. P., et al. 1977. "Literature Survey and Preliminary Evaluation of Streambank Protection Methods," Technical Report No. H-77-9, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Kuenzler, E. J., et al. 1977. "Water Quality in North Carolina Coastal Plain Streams and Effects of Channelization," Report No. 127, Water Resources Research Institute of the University of North Carolina, Raleigh, N. C.

Leedy, D. L., Maestro, R. M., and Franklin, T. M. 1978. "Planning for Wildlife in Cities and Suburbs," Report No. FWS/OBS-77/66, Office of Biological Services, U. S. Fish and Wildlife Service, Washington, D. C.

Leopold, L. B., Wolman, M. G., and Miller, J. P. 1964. Fluvial Processes in Geomorphology, Freeman, San Francisco, Calif.

Lund, J. A. 1976. "Evaluation of Stream Channelization and Mitigation on the Fishery Resources of the St. Regis River, Montana," Report No. FWS/OBS-76/07, Office of Biological Services, U. S. Fish and Wildlife Service, Washington, D. C.

Mann, R., et al. 1975. "Landscape Concept Development for Confined Dredged Material Sites," Contract Report D-75-5, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Marvin Springer and Associates. 1973. "Recreational Appendix Report, Elm Fork Flood Control Project, Dallas and Denton Counties, Texas," Preliminary report prepared for U. S. Army Engineer District, Fort Worth, Tex.

Marzolf, G. R. 1978. "The Potential Effects of Clearing and Snagging on Stream Ecosystems," Report No. FWS/OBS-78/14, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

May, B. 1972. "Evaluation of Mitigation Measures in Fisher River, Wolf Creek, and Fortine Creek, 1969-1972," State of Montana Fish and Game Department, Helena, Mont.

McCall, J. D., and Knox, R. F. 1978. "Riparian Habitat in Channelization Projects," Proceedings of the Symposium on Strategies for Protection and Management of Floodplain Wetlands and other Riparian Ecosystems, General Technical Report, GTRW012, Forest Service, U. S. Department of Agriculture, Washington, D. C.

McClellan, T. J. 1970. "Fish Passage Through Highway Culverts," U. S. Department of Transportation, Federal Highway Administration, Office of Engineering, Portland, Oreg.

McConnell, C. A., et al. 1980. "Stream Renovation Alternatives: The Wolf River Story," Journal of Soil and Water Conservation, Vol 35, No. 1, pp 17-20.

Mertes, J. D., et al. 1972. "Trinity River Greenway, A Prototype," Publication No. WRC 72-3, The Water Resources Center, Texas Tech University, Lubbock, Tex.

Morisawa, M. E. 1968. Streams: Their Dynamics and Morphology. McGraw-Hill, New York, N.Y.

Montalbano, F., et al. 1979. "The Kissimee River Channelization: A Preliminary Evaluation of Fish and Wildlife Mitigation Measures," The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats, General Technical Report RM-65, Forest Service, U. S. Department of Agriculture, Fort Collins, Colo.

Mullan, J. W. 1962. "Is Stream Improvement the Answer?" West Virginia Conservation, Vol 26, No. 6, pp 25-30.

National Wildlife Federation. 1974. Gardening with Wildlife, National Wildlife Federation Publications, 1412 16th St. N.W., Washington, D. C.

Nelson, R. W., Horak, G. C., and Olson, J. E. 1978. "Western Reservoir and Stream Habitat Improvements Handbook," Report No. FWS/OBS-78/56, U. S. Fish and Wildlife Service, Washington, D. C.

Nunnally, N. R., and Keller, E. 1979. "Use of Fluvial Processes to Minimize Adverse Effects of Stream Channelization," Report No. 144, Water Resources Research Institute, University of North Carolina, Raleigh, N. C.

Parker, G., and Andres, D. 1976. "Detrimental Effects of River Channelization," Proceedings of the Symposium on Inland Waters for Navigation, Flood Control, and Water Diversions, American Society of Civil Engineers, pp 1248-1266.

Parrish, J. D., et al. 1978. "Stream Channel Modification in Hawaii, Part D: Summary Report," Report No. FWS/OBS-78/19, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Pfankuch, D. J. 1978. "Stream Reach Inventory and Channel Stability Evaluation," Forest Service, Northern Region, U. S. Department of Agriculture, U. S. Government Printing Office: 1978-797-059/31 Region 10.

Schemnitz, S. D., ed. 1980. Wildlife Management Techniques Manual, Fourth Edition, The Wildlife Society, Washington, D. C.

Schumm, S. A. 1971. "Fluvial Geomorphology: Channel Adjustment and River Metamorphosis," River Mechanics, H. W. Shen, ed., Vol 1, Fort Collins, Colo., pp (5-1)-(5-22).

Schumm, S. A. 1972. "Experimental Study of Channel Patterns," Geological Society of America Bulletin, Vol 83, No. 6, pp 1755-1770.

Schumm, S. A. 1977. The Fluvial System, John Wiley and Sons, New York, N. Y.

Schumm, S. A. 1981. "Evolution and Response of the Fluvial System, Sedimentologic Implications," Society of Economic Paleontologists and Mineralogists Special Publication No. 31, pp 19-29.

Shen, H. W., ed. 1971. River Mechanics. H. W. Shen, Fort Collins, Colo.

Shen, H. W., et al. 1981. "Methods for Assessment of Stream-Related Hazards to Highways and Bridges," Report No. FHWA/RD-80/160, Federal Highway Administration, Office of Research and Development, Environmental Division, Washington, D. C.

Shields, F. D., and Palermo, M. R. 1981. "Assessment of Environmental Considerations in the Design and Construction of Waterway Projects," Draft Technical Report, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Smardon, R. C. 1979. "Prototype Visual Impact Assessment Manual," School of Landscape Architecture, State University of New York-Syracuse, Syracuse, N. Y.

Stone, E. H. 1979. "Visual Resource Management," Landscape Architecture Technical Information Series, Vol 1, No. 2, American Society of Landscape Architects.

Stuart, T. A. 1953. "Spawning Migration, Reproduction, and Young Stages of Loch Trout," Freshwater and Salmon Fisheries Research Station, Her Majesty's Stationery Office, Edinburgh, Scotland.

Tarzwell, C. M. 1932. "Trout Stream Improvement in Michigan," Transactions of the American Fisheries Society, Vol 61, pp 48-57.

Tarzwell, C. M. 1936. "Experimental Evidence on the Value of Trout Stream Improvement in Michigan," Transactions of the American Fisheries Society, Vol 66, pp 177-187.

U. S. Army Engineer District, Detroit. 1974. "Flood Control on Saginaw River, Michigan, and Tributaries, Flint River at Flint," Letter Report on Project Beautification and Section C-2, Detroit, Mich.

U. S. Army Engineer District, Fort Worth. 1979. "Boggy Creek, Austin, Texas, Colorado River and Tributaries, Texas," Interim Report, Volume II, Appendix 1, Fort Worth, Tex.

U. S. Army Engineer District, Honolulu. 1975. "Final Environmental Statement, Flood Control and Allied Purposes, Iao Stream, Maui, Hawaii," Honolulu, Hawaii.

U. S. Army Engineer District, Huntington. 1980. "Scioto River at North Chillicothe, Main Report and Environmental Impact Statement," Huntington, W. Va.

U. S. Army Engineer District, Kansas City. 1972. "Channel Improvement Project, Little Blue River Channel and Lake City Area Improvement Vicinity of Kansas City, Missouri," Design Memorandum No. 1, General, Kansas City, Mo.

U. S. Army Engineer District, Los Angeles. 1973. "Indian Bend Wash, Maricopa County, Arizona," Final Environmental Statement, Los Angeles, Calif.

U. S. Army Engineer District, Memphis. 1979. "Supplement No. 1 to General Design Memorandum No. 103, Little River Drainage," Memphis, Tenn.

U. S. Army Engineer District, Mobile. 1978. "Detailed Project Report on Burnt Corn and Murder Creeks in the Vicinity of Brewton and East Brewton, Alabama," Mobile, Ala.

U. S. Army Engineer District, Omaha. 1977. "Chatfield Lake, Colorado, South Platte River, Chatfield Dam to Denver," Statement of Findings, Omaha, Nebr.

U. S. Army Engineer District, San Francisco. 1980. "Corte Madera Creek Flood Control Project Unit 4," Revised Environmental Impact Statement (Final), San Francisco, Calif.

U. S. Army Engineer District, Seattle. 1965. "Libby Dam Project, Great Northern Line Change, Fish and Wildlife Facilities in Channel Changes," Supplement to Design Memorandum 5, Seattle, Wash.

U. S. Army Engineer District, Tulsa. 1976. "Halstead Local Flood Protection Project, Halstead, Kansas," Revised Draft Environmental Impact Statement, Tulsa, Okla.

U. S. Army Engineer District, Vicksburg. Undated. "Flood Control/Mississippi River and Tributaries, Yazoo Basin-Big Sunflower River, Steele Bayou, Item 55-A, Channel Improvement, Issaquena and Washington Counties, Mississippi, Item 55-A," Specifications, Vicksburg, Miss.

U. S. Department of Agriculture Forest Service. 1969. Wildlife Habitat Improvement Handbook, Forest Service Handbook FSH 2609.11, Washington, D. C.

U. S. Department of Agriculture Soil Conservation Service. 1975. "Prairie Creek (Vigo) Watershed Project, Indiana," Final Environmental Impact Statement, Indianapolis, Ind.

U. S. Department of Agriculture Soil Conservation Service. 1977. "Design of Open Channels," Technical Release No. 25, Washington, D. C.

U. S. Geological Survey. 1977. "Water Resources Data for Alabama, Water Year 1977," Water-Data Report AL-77-1, Washington, D. C.

Walker, J. J. 1979. "Environmental Considerations in Engineering Design," The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats, General Technical Report RM-65, Forest Service, U. S. Department of Agriculture, Fort Collins, Colo.

Watts, F. J. 1974. "Design of Culvert Fishways," Water Resources Research Institute, Moscow, Idaho.

Wharton, C. H., and Brinson, M. M. 1978. "Characteristics of Southeastern River Systems," Proceedings of the Symposium on Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, General Technical Report, GTRW012, Forest Service, U. S. Department of Agriculture, Washington, D. C.

White, R. J. 1973. "Stream Channel Suitability for Coldwater Fish," Wildlife and Water Management: Striking a Balance, Soil Conservation Society of America, Ankeny, Iowa.

White, R. J., and Byrnildson, O. M. 1967. "Guidelines for Management of Trout Stream Habitat in Wisconsin," Technical Bulletin No. 39, Wisconsin Department of Natural Resources, Division of Conservation, Madison, Wis.

Whitlow, T. H., and Harris, R. W. 1979. "Flood Tolerance in Plants: A State-of-the-Art Review," Technical Report No. E-79-2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Whitton, B. A., ed. 1975. River Ecology, University of California Press, Los Angeles, Calif.

Willeke, G. E. 1981. "The George Palmiter River Restoration Techniques," Final Report (in preparation), Institute of Environmental Sciences, Miami University, Oxford, Ohio.

Winger, P. V., et al. 1976. "Evaluation Study of Channelization and Mitigation Structures in Crow Creek, Franklin County, Tennessee, and Jackson County, Alabama," U. S. Soil Conservation Service, Nashville, Tenn.

Winner, M. D., and Simmons, C. E. 1977. "Hydrology of the Creeping Swamp Watershed, North Carolina, with Reference to the Potential Effects of Stream Channelization," U. S. Geological Survey Water Resources Investigations 7726, Raleigh, N. C.

Witten, A. L., and Bulkley, R. V. 1975. "A Study of the Effects of Stream Channelization and Bank Stabilization on Warmwater Sportfish in Iowa: Subproject No. 2. A Study of the Impact of Selected Bank Stabilization Structures on Game Fish and Associated Organisms," Report No. FWS/OBS-76/12, Office of Biological Services, U. S. Fish and Wildlife Service, Department of the Interior, Washington, D. C.

Yearke, L. W. 1971. "River Erosion Due to Channel Relocation," Civil Engineering, Vol 41, pp 39-40.

APPENDIX A: REVIEW OF DOCUMENTED EXPERIENCE WITH STREAM HABITAT STRUCTURES

Introduction

1. Although there is a great deal of literature on the use of habitat restoration structures in natural stream channels, relatively few investigators have documented designs for and biological effectiveness of habitat structures placed in modified stream channels. Below is a brief review of several studies of the effectiveness of habitat structures in enlarged and/or relocated stream channels. Other studies that include both structural and biological information may be available; however, these were the only ones located within the limited timeframe of this research. Additional information may be obtained from the references cited and personal communications with the authors and representatives of the constructing agencies.

Corps Projects

Fisher River

2. Project description. The Fisher River is a rocky Montana trout stream with a mean daily flow of about 520 cfs, which was straightened and enlarged to allow construction of a railroad embankment. The construction was necessary to relocate a rail line displaced by the construction of the Libby Dam and Lake Koocanusa. The channel was modified to convey the 50-year event (7800 cfs)* with a slope of about 0.007 (Keown 1981).**

3. Habitat structures. Several rock sills or groins were constructed in the modified channel to reduce velocities, concentrate low flows, prevent erosion, control channel grade, and provide aquatic

---

* Personal communication from Mr. George Ristan, U. S. Army Engineer District, Seattle, Wash., to the author.

** References cited in this appendix are listed in the References section at the end of the main text.

habitat. The sills were constructed of large rock placed over a 1-ft-thick layer of gravel bedding and were spaced 125 ft apart to create pools 1 ft deep (Figures A1 through A3). The structures were keyed into the channel bed 2.5 ft below grade to prevent undercutting and extended 2 ft above channel grade to provide fish with resting pools and reduce stream velocities. The sills were designed with a weir or notch to concentrate low flows for fish movement. Notches were placed off center to keep flows away from an adjacent railroad embankment. Rock size was selected for stability in velocities of 10 to 14 ft/sec, but structures were designed to fail at a discharge lower than the design (50-year) event. Since they were designed to fail during high flows, the effect of the sills on channel capacity was not considered. Rocks ranged from 25 to 1000 lb, with at least 75 percent weighing from 100 to 1000 lb and at least 40 percent weighing more than 400 lb. Structures constructed later in the project were built with stones weighing between 200 and 2000 lb, with 50 percent weighing more than 1000 lb due to the early failure of some of the first structures. The structures were initially designed for a 15-year period (Seattle District 1965); inspection of the structures a year after construction indicated that their average life would probably be less than 15 years. After 14 years, several of the structures were still intact, while riffle areas marked the remnants of others (Keown 1981).

4. Biological effectiveness. May (1972) reported the results of a 3-year monitoring effort that followed construction of the sills. Although the structures were effective in creating shallow pools and stabilizing the channel bed, they produced considerably more sucker habitat than trout habitat. Trout habitat would have been enhanced more had the channel provided more streambank area where cover was associated with current velocities greater than 1 ft/sec. Trout populations were adversely impacted by the increasing sediment loads and loss of riparian vegetation caused by channel relocation and railroad embankment construction. Trout populations in the areas of the Fisher River influenced by construction declined during the study period, while trout populations in an uninfluenced control area appeared to increase during the same period.

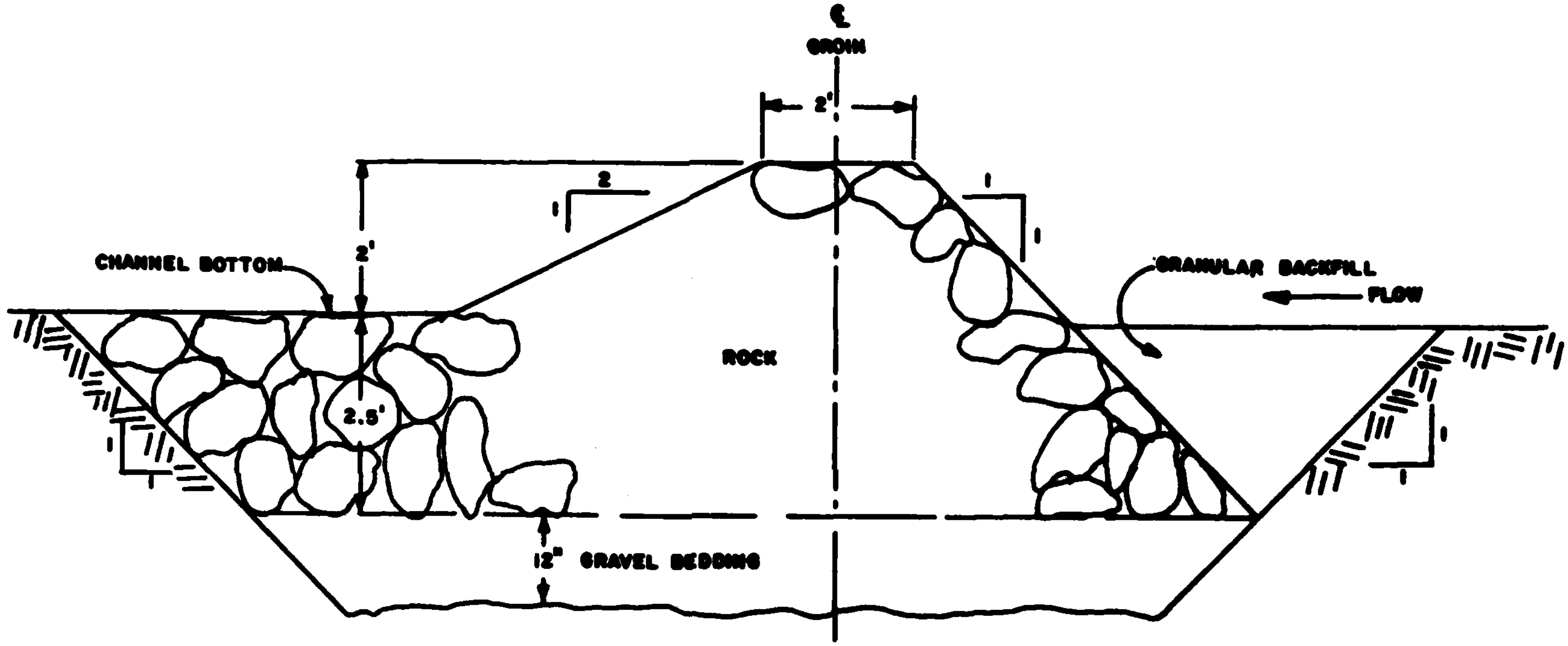


Figure A1. Profile view of rock sill installed in Fisher River for fish habitat restoration (Keown 1981)

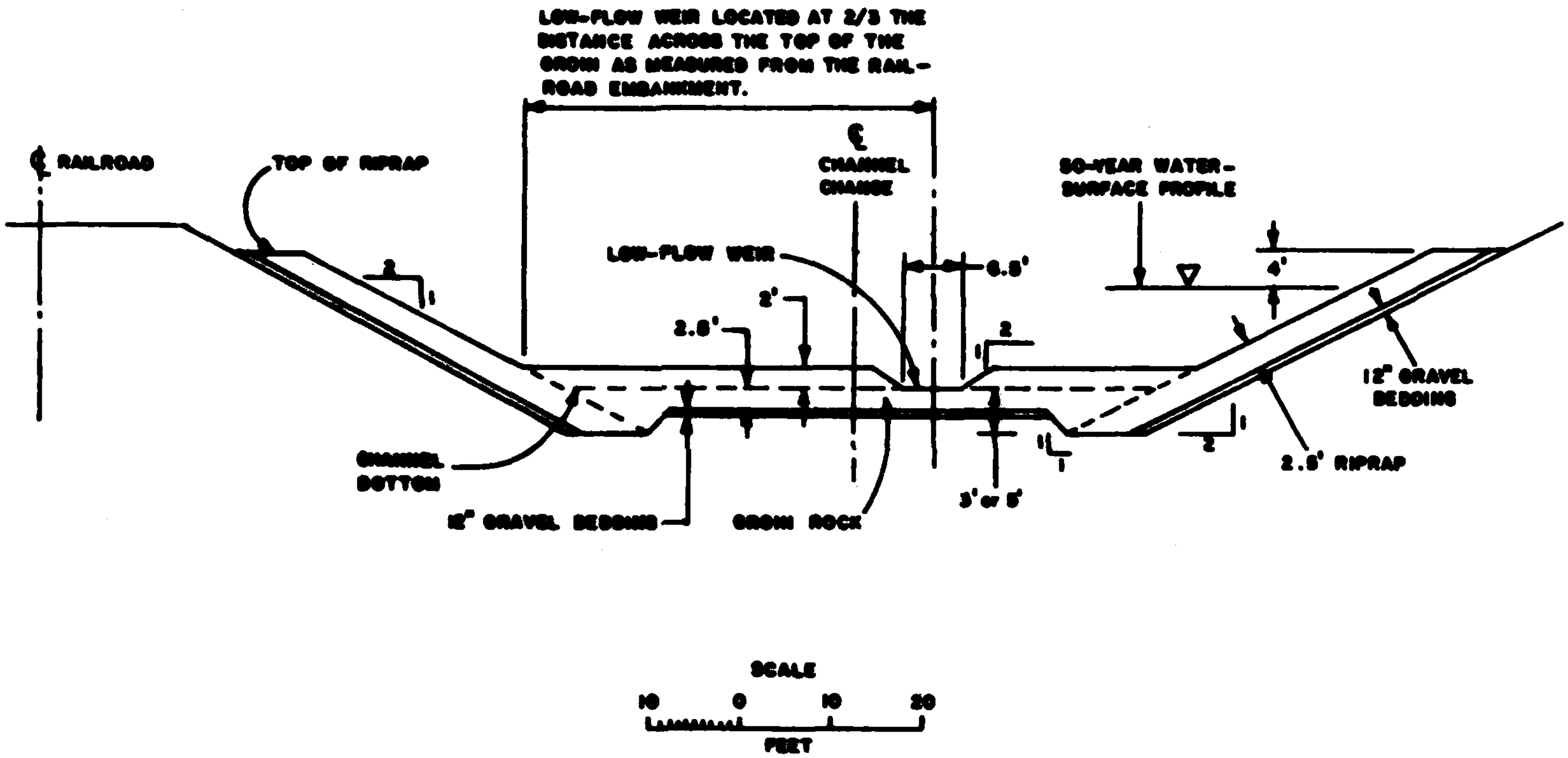


Figure A2. Typical cross-channel view of Fisher River rock sill (Keown 1981)

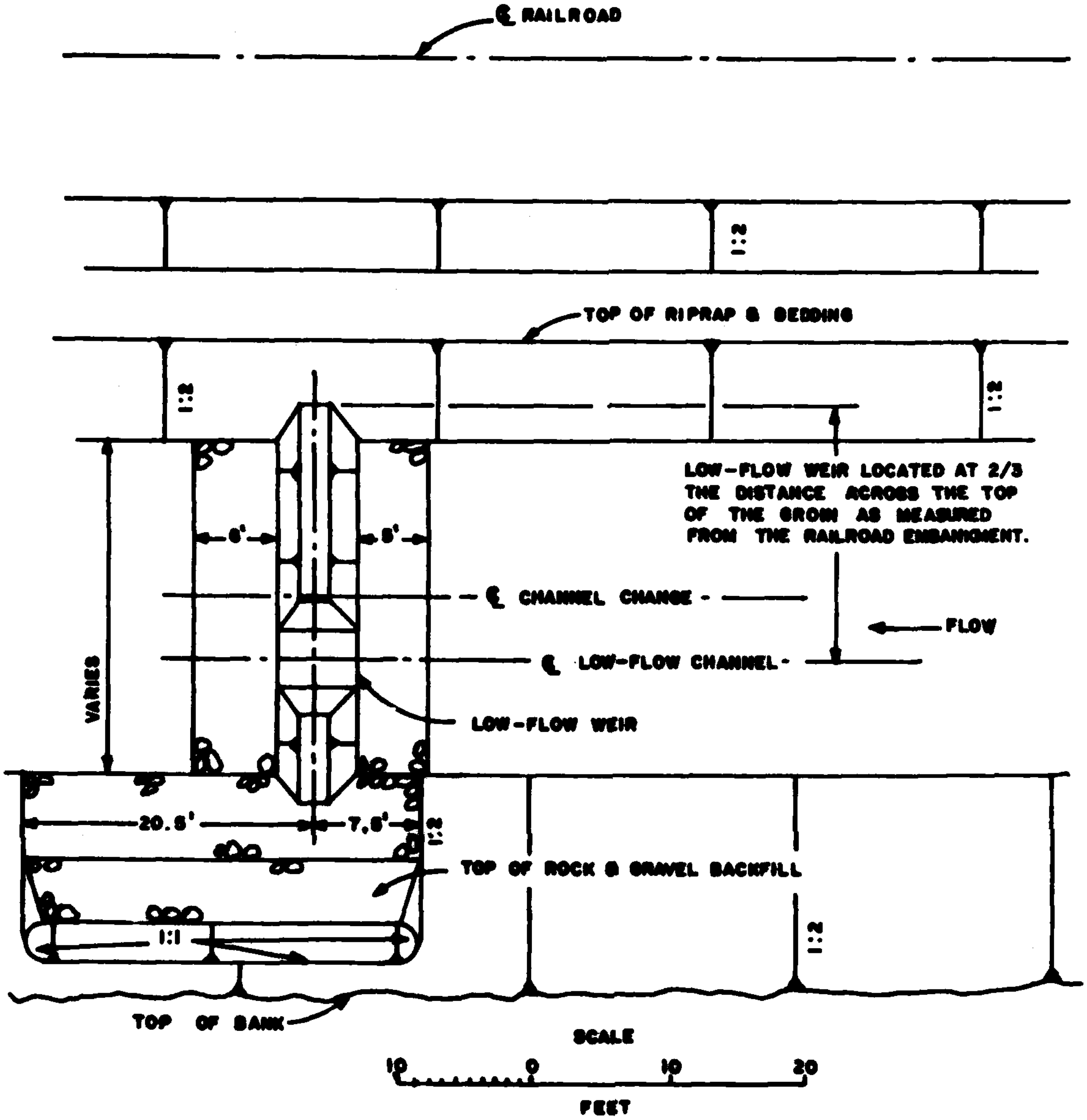


Figure A3. Typical plan view of Fisher River rock sill and channel (Keown 1981)

Rapid Creek

5. Project description. Rapid Creek is a trout stream that flows through Rapid City, South Dakota. Although the stream channel had been modified several times in the past, it supported a highly productive and popular trout fishery. Trout habitat in a 3000-ft reach of Rapid Creek had been severely damaged during channel modification for

flood-control due to the occurrence of a flood event and the operation of earthmoving machinery in the channel. Plans called for the channel to be enlarged to convey a 50-year event (500 cfs) by excavation of the banks only, with no modification of the existing normal flow channel. Mean daily flow for a 33-year period of record was 62 cfs, and channel slope through the modified reach was about 0.005. Bed material was gravel and rubble, with enough fine gravel to provide good spawning areas for trout.*

6. Habitat structures. Deflectors and revetment structures were installed in the damaged reach to create a narrower, deeper, meandering channel during low flows (Figure A4). The deflectors and revetments were constructed of a 6-ft layer of 1- to 3-ft rock (1 ton/linear ft) over small rock and gravel fill taken from the streambed. The structures extended 1.5 ft above the channel grade and were keyed into the bed 1.5 ft. Tiebacks were extended into the bank 3 to 4 ft. The hydraulic effects of the structures on high flows were judged to be insignificant since the structures have such low profiles.*

7. Biological effectiveness. A study of the effects of the structures on aquatic habitat and fish populations is currently under way, and preliminary results indicate the structures are providing good habitat and speeding trout repopulation of the modified reach.*

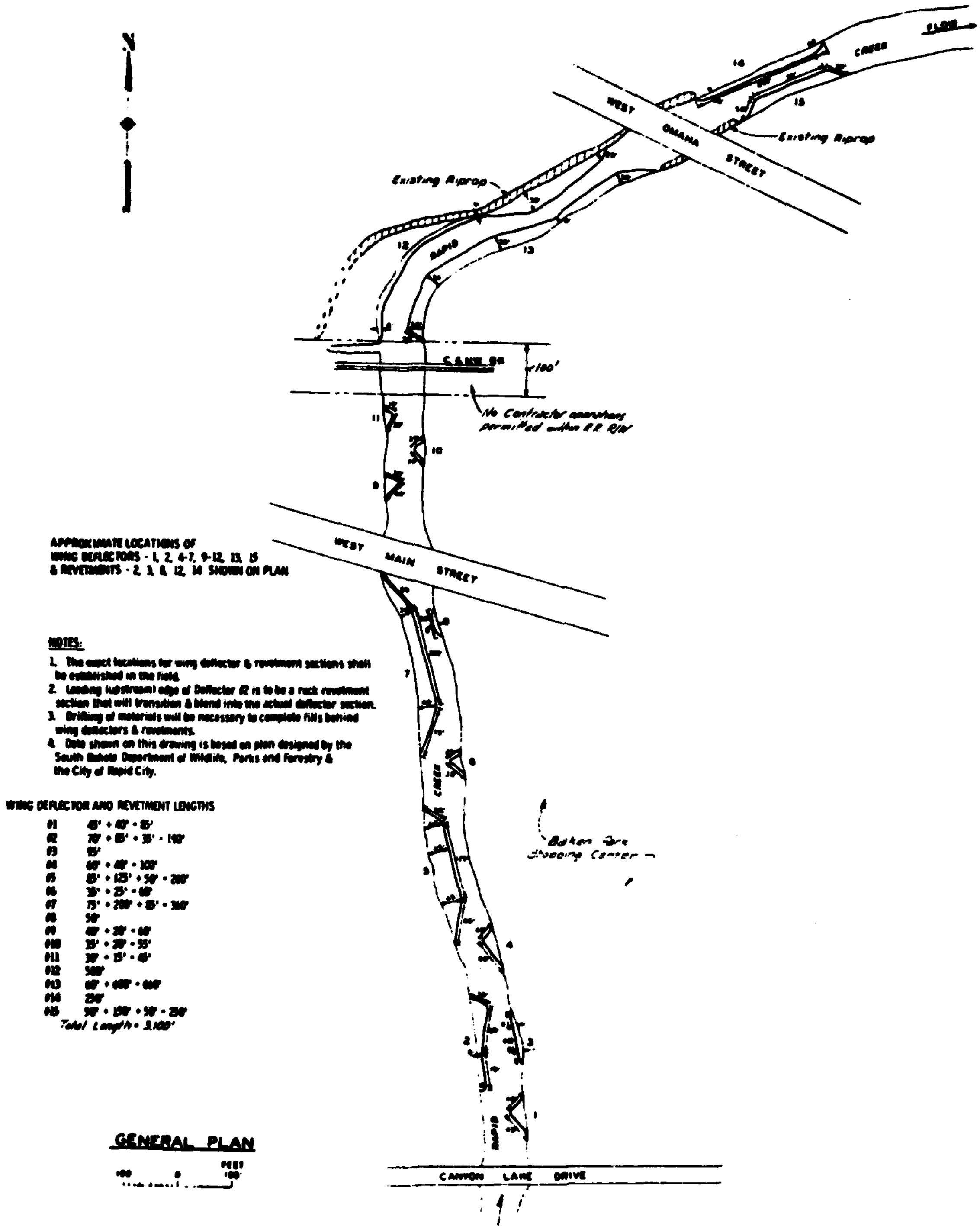
State Projects

Weber River

8. Project description. Several reaches of the Weber River, Utah, shorter than 1 mile were realigned to allow for highway construction. The modified reaches had trapezoidal cross sections with 70-ft bottom widths, 1H:1V side slopes, and an average channel slope of 0.005. The constructed reaches were designed to convey a flow of 5400 cfs, with an

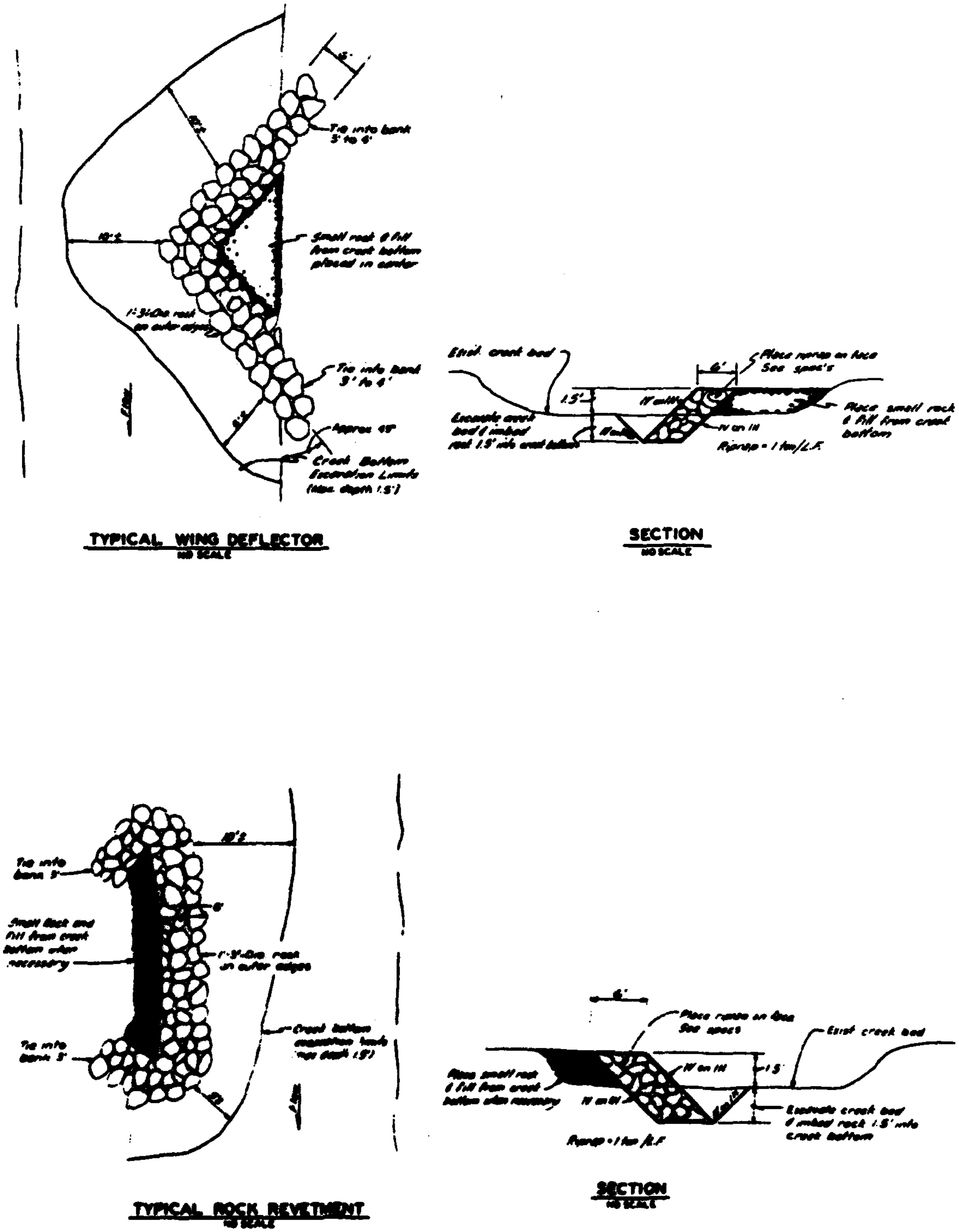
---

* Personal communications from Mr. Ronald Glover, South Dakota Department of Game, Fish, and Parks, Rapid City, South Dakota, to the author; and Messrs. Dick Gordon and Gerry Mick , U. S. Army Engineer District, Omaha, Nebr., to the author.



a. River

Figure A4. Rapid Creek habitat structures, Rapid Creek, Rapid City, South Dakota Flood Protection Project, drawing number CY25 2-370E1, January 1979, Omaha District (Continued)



b. Sections

Figure A4. (Concluded)

average velocity of about 10 ft/sec; normal flow average velocities were 3 to 5 ft/sec. Mean daily flow was about 255 cfs, but low flows less than 10 cfs were common. During the study, flows varied from 0 to 1800 cfs. Flows were regulated by an upstream reservoir, and the bed material was rubble and gravel (Barton and Winger 1973, Barton et al. 1971).

9. Habitat structures. Some 59 structures were installed in five modified reaches with a total length of 1.6 miles scattered along 7 to 8 miles of the river. Forty-five of these structures were either gabion deflectors or gabion check dams (Figures A5 and A6) which were keyed into the bed 2.5 to 3 ft; crest heights were 1.5 to 2 ft above channel grade and crest widths were 4 ft.* About 150 random rocks weighing 1 to 4 tons were also placed in the modified sections (Barton and Winger 1973, Barton et al. 1971).

10. Biological effectiveness. Scour downstream from most of the structures produced vertical relief quite similar to that in the natural channel. Two to three years after modification, numbers, density, and diversity of macroinvertebrates and fish in the modified reaches were similar to unchanged reaches. Water temperatures were not significantly affected by removal of riparian vegetation since the major influence on the water temperature during the summer was the upstream reservoir. Only ten of the structures were ineffective in producing the desired habitat. In general, the ineffective structures were placed in areas of low velocity, i.e. just upstream from a check dam or on the inside of a bend, and were covered by sediment deposition. Some of the gabion wire baskets failed due to corrosion. Riprap structures were found to be preferrable to gabion structures due to effectiveness and cost, but the relative cost of gabions and large riprap varies from one region of the country to another. Biological recovery of the modified sections was aided by the presence of coarse substrate and the proximity of unaltered reaches (Barton and Winger 1973, Barton et al. 1971).

---

* Personal communications from Dr. J. S. Barton, Department of Civil Engineering, Brigham Young University, Provo, Utah, to the author.

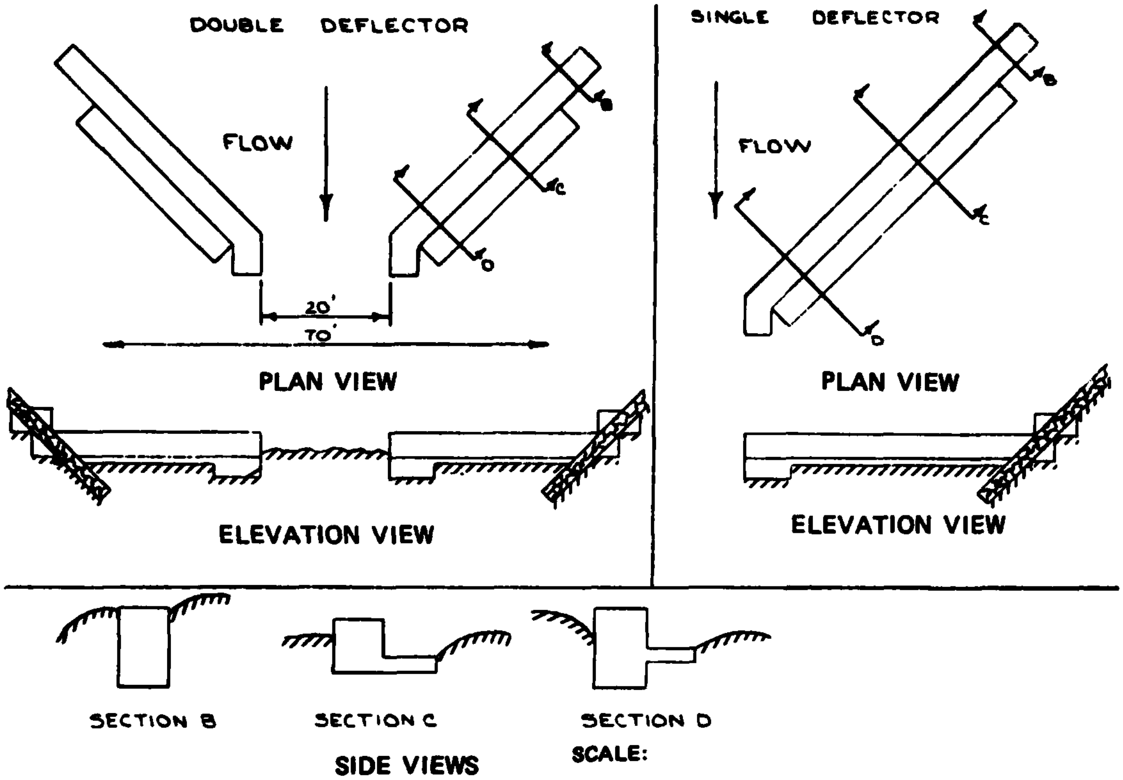


Figure A5. Details of gabion deflectors installed in Weber River (Barton et al. 1971)

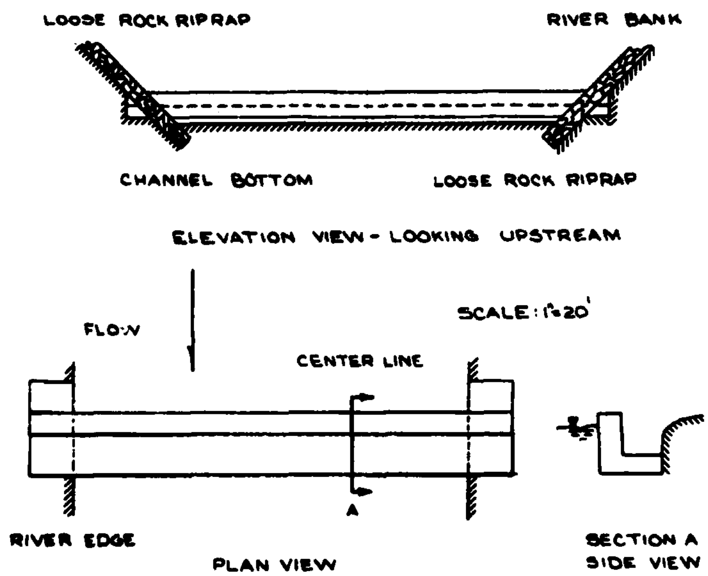


Figure A6. Details of gabion check dams installed in Weber River (Barton et al. 1971)

Olentangy River

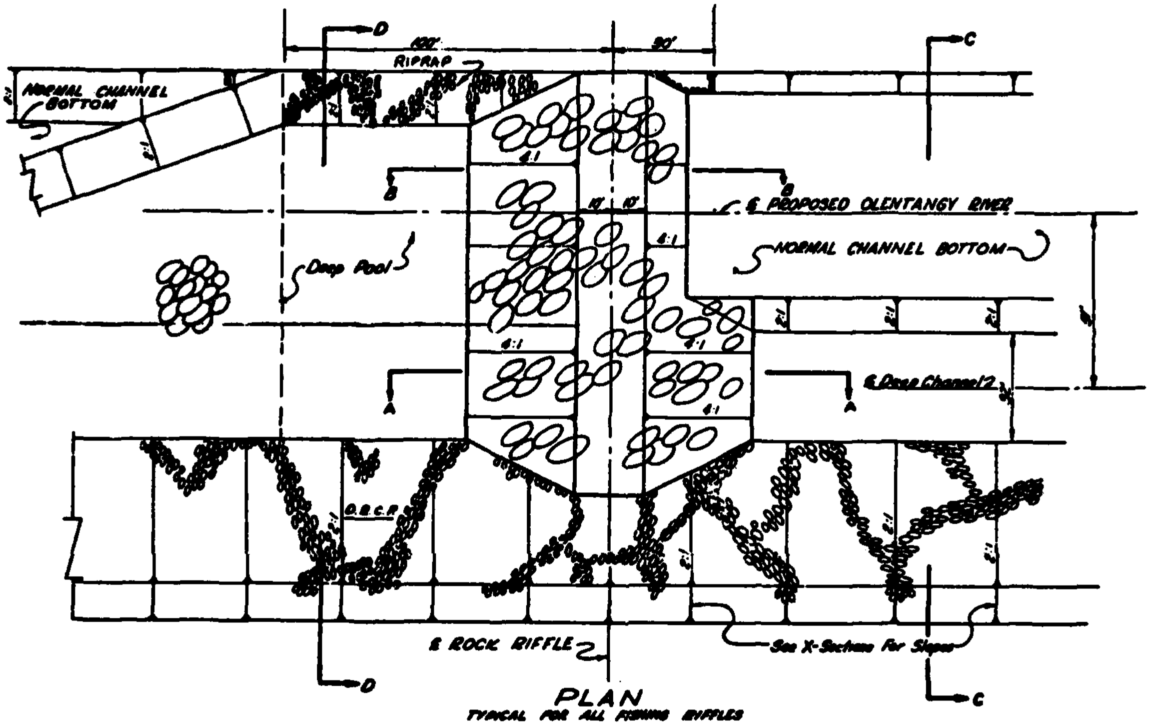
11. Project description. A 4400-ft-long reach of the Olentangy River, Ohio, was relocated in a straight channel to allow for highway construction. The new channel had a low-flow channel adjacent to the steep, shady east bank and bordered on the west side by a wide berm (Figures A7 and A8). At normal flow, both the low-flow channel and the berm were inundated, giving an average channel width of about 120 ft. The main purpose of the 32-ft wide low-flow channel was to provide deep-water habitat. Bed materials in the modified reach were clay, silt, sand, and gravel, and the channel slope was 0.0007. Mean daily flow was about 460 cfs, minimum flow was 8.5 cfs, and maximum flow 16,500 cfs, all for a 20-year period of record. The modified channel was designed to convey 8 to 10,000 cfs.* Flows were regulated by an upstream reservoir (Griswold et al. 1978).

12. Habitat structures. Embankments of rock over earthen fill (artificial riffles) were placed in the low-flow channel (Figure A7). The embankments had a top width of 20 ft and were placed on centers seven channel widths (840 ft) apart. The crest elevation of the riffles was about 0.5 ft above the water surface at normal flow. The deepest portions of the low-flow channel were about 80 ft deep at normal flow. Rock size for the structures was specified simply as 85 percent by weight larger than 9 in. However, the structures were actually built with stones mostly 18 in. or larger. The structures have remained in place, and pools associated with them have remained deep for more than ten years.

13. Biological effectiveness. Griswold et al. (1978) reported that the artificial riffles and associated deep pools allowed fish and macroinvertebrate populations to recover in four years to levels higher than similar populations in a modified reach with no habitat structures had attained in 25 years. Edwards (1977) reported that the structures had a generally positive effect on the abundance and biomass of fish in

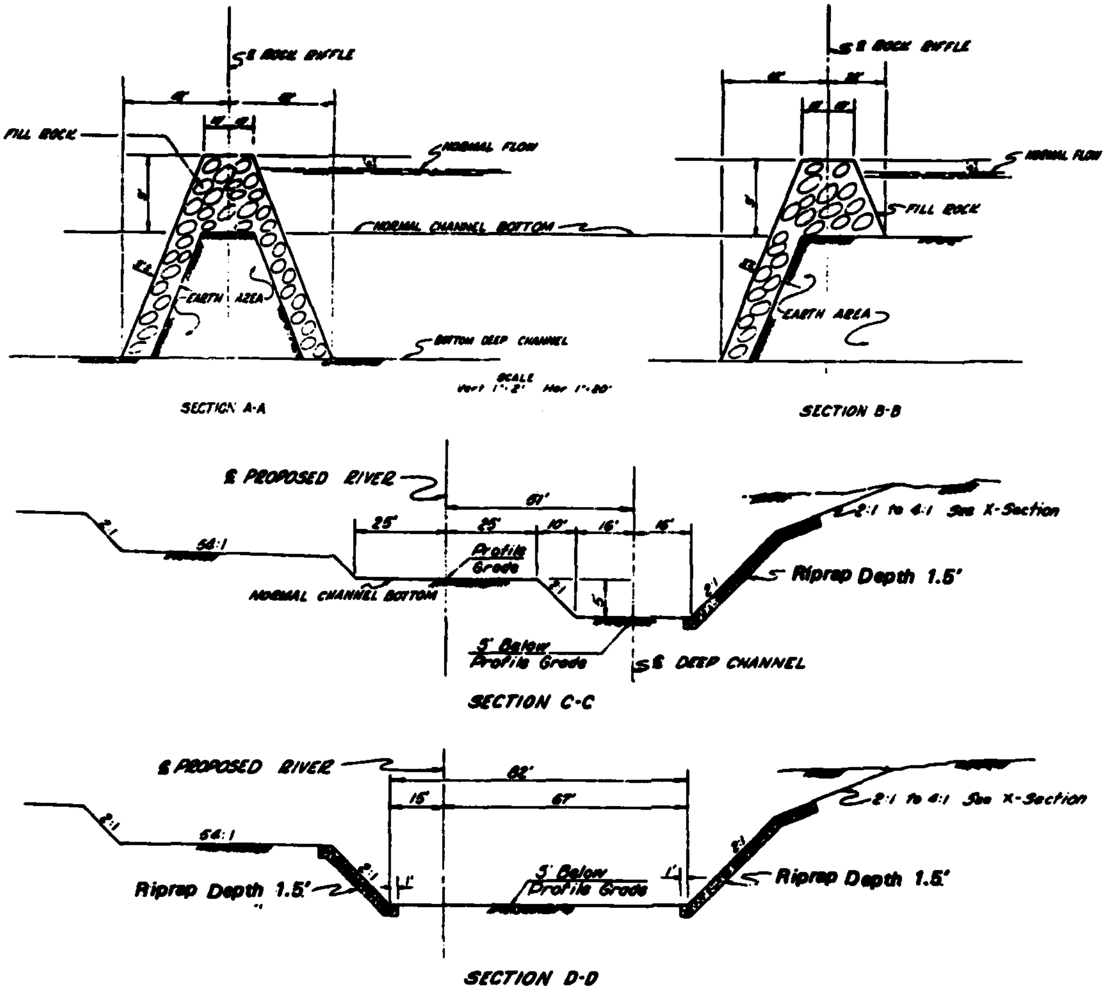
---

* Personal communication from Mr. Thomas E. Linkous, Ohio Department of Transportation, Columbus, Ohio, to the author.



a. Plan view

Figure A7. Details of relocated channel and rock sills installed in the Olentangy River (drawing courtesy of Ohio Department of Transportation) (Continued)



b. Sections

Figure A7. (Concluded)

(Courtesy of Ohio Cooperative Fishery Research Unit, U.S. Fish and Wildlife Service, Columbus, Ohio)

Figure A8. Relocated reach of the Olentangy River

the relocated channel when compared to the older modified reach with no habitat structures. The level of fisherman use in the area of the structures was high due to the easy access and availability of desirable gamefish (Griswold et al. 1978). In fact, creel censuses revealed approximately ten times as many fish were being caught from the reach with structures as were caught from a reach that was modified 25 years before, but had no structures.

U. S. Soil Conservation Service (SCS) Projects

Crow Creek

14. Project description. Crow Creek was an SCS small watershed project in southern Tennessee and northern Alabama. The creek had been enlarged and straightened for agricultural flood control. The newly modified channel was about 9 miles long and had a bankfull capacity of about 2000 cfs, a slope of about 0.001, and widths ranging from 30 to 60 ft. Discharge extremes for a 2-year record were 7260 cfs and 6.6 cfs, and low flows were in the range of 10 to 20 cfs (U. S. Geological Survey

1977). Bed material generally ranged from bedrock and rubble to gravel and sand, but clay and silt were found in some pools. Gravel and sand were the most common bed materials throughout the modified reach.

15. Habitat structures. Thirteen grade-stabilization structures (sills) were installed in the modified channel to maintain channel stability and create a pool-riffle habitat. Two of the structures were riprap check dams with a sheet-piling cutoff, and the others were check dams or double deflectors made of timbers and riprap; some of the check dams (sills) had crests made of reinforced concrete. A representative design is shown in Figures A9 and A10. All structures have remained in place for several years without failing, although riprap was displaced from around one of the sheet-piling structures four years after construction. Riprap was used to protect banks in some reaches (Winger et al. 1976).

16. Biological effectiveness. Winger et al. (1976) studied the modified reaches for two years and found that diversity and abundance of fish populations were directly related to habitat diversity. Reaches with well-developed riffle-pool complexes had more diverse and abundant fish populations than reaches which were mostly pool. Most of the habitat structures were effective in producing the desired riffle-pool sequence.

17. Properly spaced structures with proper crest elevations produced short pools upstream and small scour holes downstream; material deposited downstream of the scour holes formed riffles. Some of the structures were placed too close together, or with crests too high, and created large pools with fewer riffle areas. These long pool reaches had fish populations that were inferior to populations of the more diverse reaches. Crest elevations for the structures may have been selected based on the designed channel invert elevation, and not on the actual channel invert elevation which possibly degraded prior to structure installation.* Riprap bank protection was observed

---

* Personal communication from Dr. Parley V. Winger, U. S. Fish and Wildlife Service, Athens, Ga., to the author.

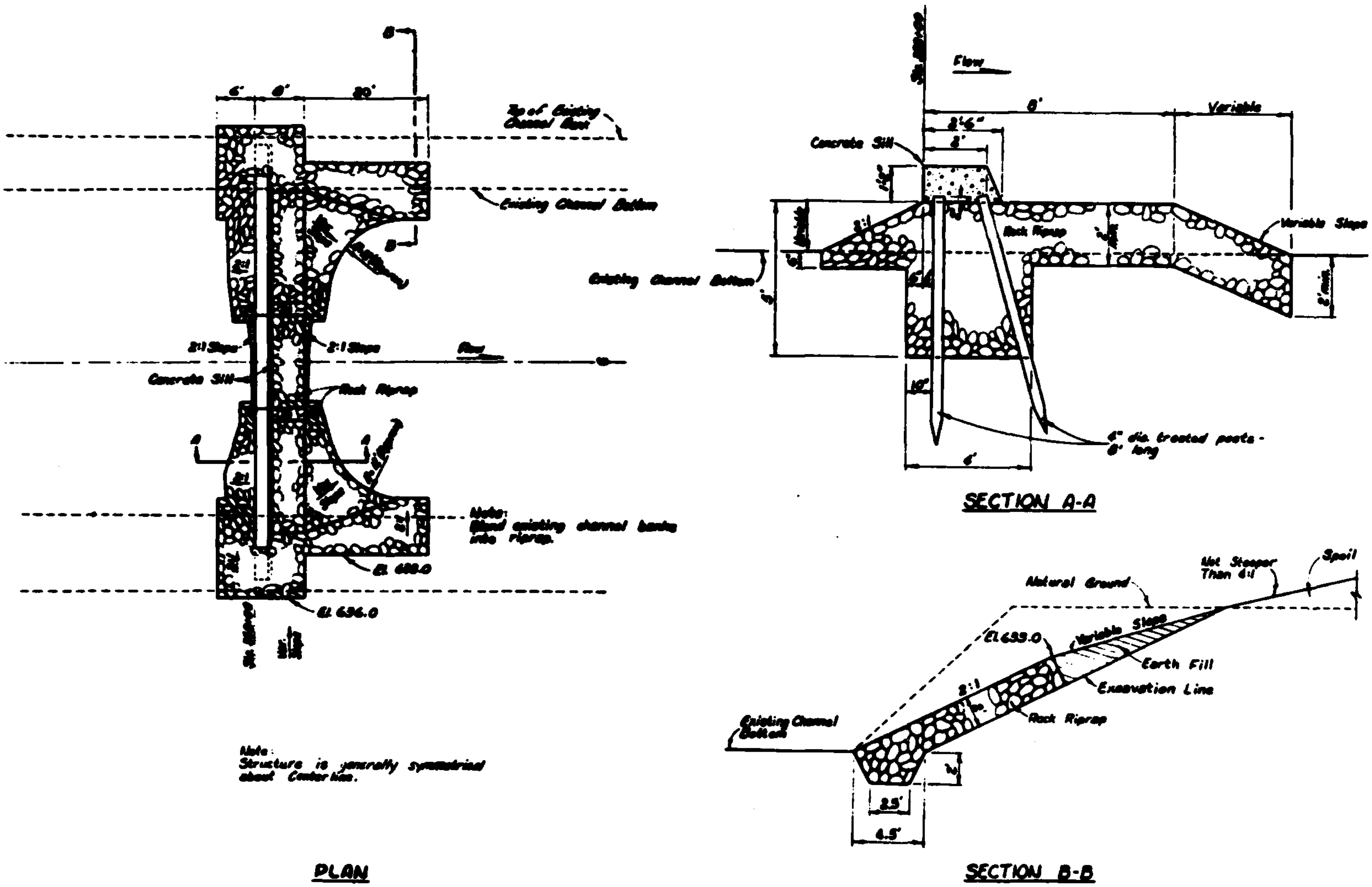


Figure A9. Plan and section of Type 3 habitat structure installed in Crow Creek, Crow Creek Watershed, Franklin and Marion Counties, Tennessee, Sheet 5 of Drawing No. 4-E-23, 633, August 1972, U. S. Department of Agriculture Soil Conservation Service

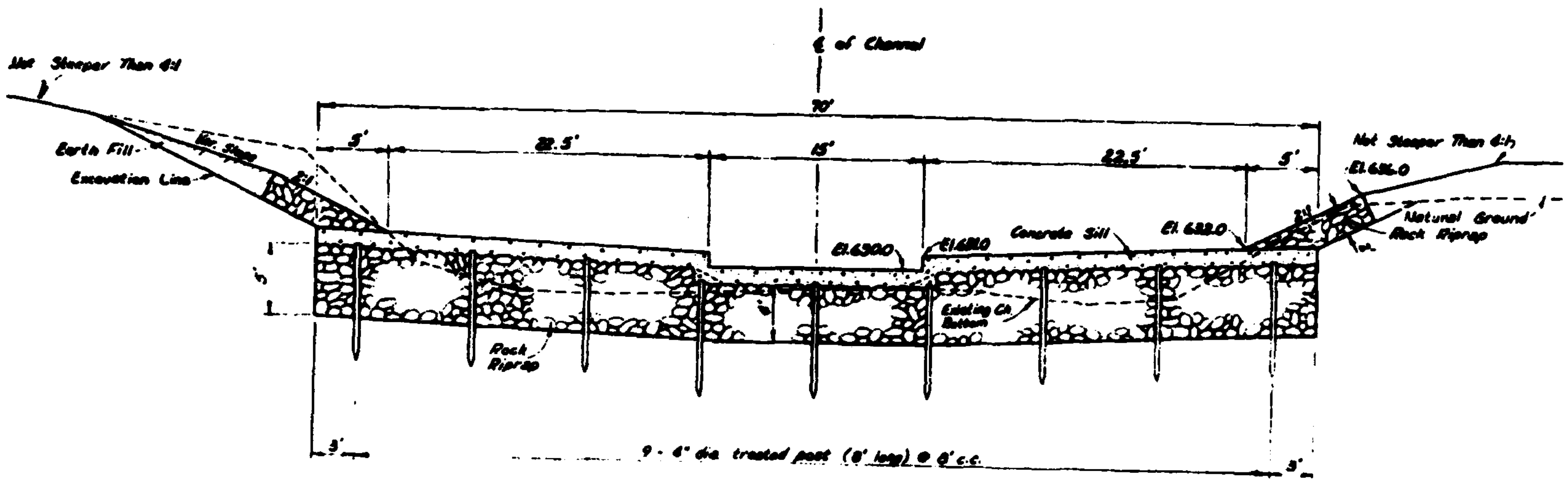


Figure A10. Profile of Type 3 habitat structure installed in Crow Creek, Crow Creek Watershed, Franklin and Marion Counties, Tennessee, Sheet 6 of Drawing No. 4-E-32, 633, August 1972, U. S. Department of Agriculture Soil Conservation Service to have a positive impact on the aquatic community, providing stable substrate for periphyton, benthos, and game fish (Winger et al. 1976).

Prairie Creek

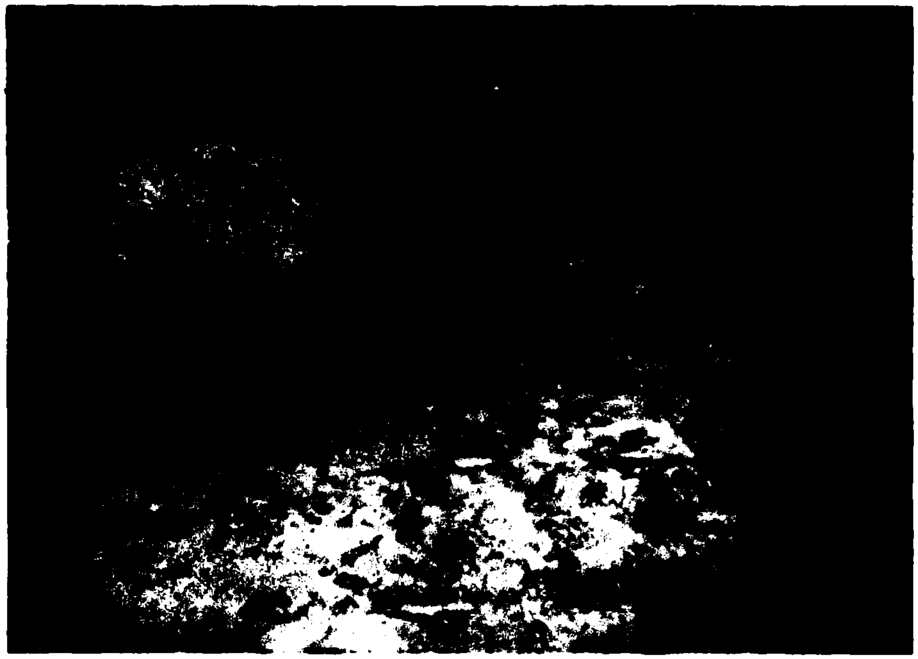
18. Project description. Prairie Creek, Indiana, was an SCS small watershed project. The creek had been enlarged and straightened for agricultural flood control. The newly modified channel was about 4.0 miles long and carried flows of 160 to 640 cfs at bankfull, with average velocities in the range of 2.4 to 3.2 ft/sec. Mean daily flow was about 25 cfs.* Channel slope was about 0.001, and bottom widths ranged from 8 to 28 ft from the upstream to the downstream reaches. Bed material was classified as silty clay, sandy clay, and gravelly sandy clay.**

19. Habitat structures. Rock sills were installed in Prairie Creek and several other similar projects to provide aquatic habitat (Figures A11 and A12). The sills were constructed of stone with a gap in the center of each structure one-third of the channel width wide. The invert of the gap was level with the upstream channel invert elevation, and a scour hole about 50 ft long was pre-excavated just downstream of the sill to a depth 3 ft below channel grade. Sides of the preformed scour hole were protected with riprap to prevent eddy scour. The crest of the sill was 2 ft above channel grade, and the structure was keyed into the channel bed 2 ft below grade. Larger stones were placed in the gap for especially critical conditions that might occur during intermediate flows. Stone gradation was between 25 and 150 lb, with 25-50 percent of the stones heavier than 100 lb. Structures were tied into the banks, and riprap was placed on both banks on either side of the sill to prevent flanking. Six structures were installed in each mile of channel for an average spacing of

---

* Personal communication from Mr. Bob Moore, U. S. Geological Survey, Indianapolis, Ind., to the author.

** Personal communication from Mr. Elias Bloom, U. S. Soil Conservation Service, Indianapolis, Ind., to the author.



a. At low flow, downstream bank protection has not been installed

b. During moderately high flow (note riprap bank protection on sides of downstream scour hole)

Figure A11. Riprap sill installed in Prairie Creek

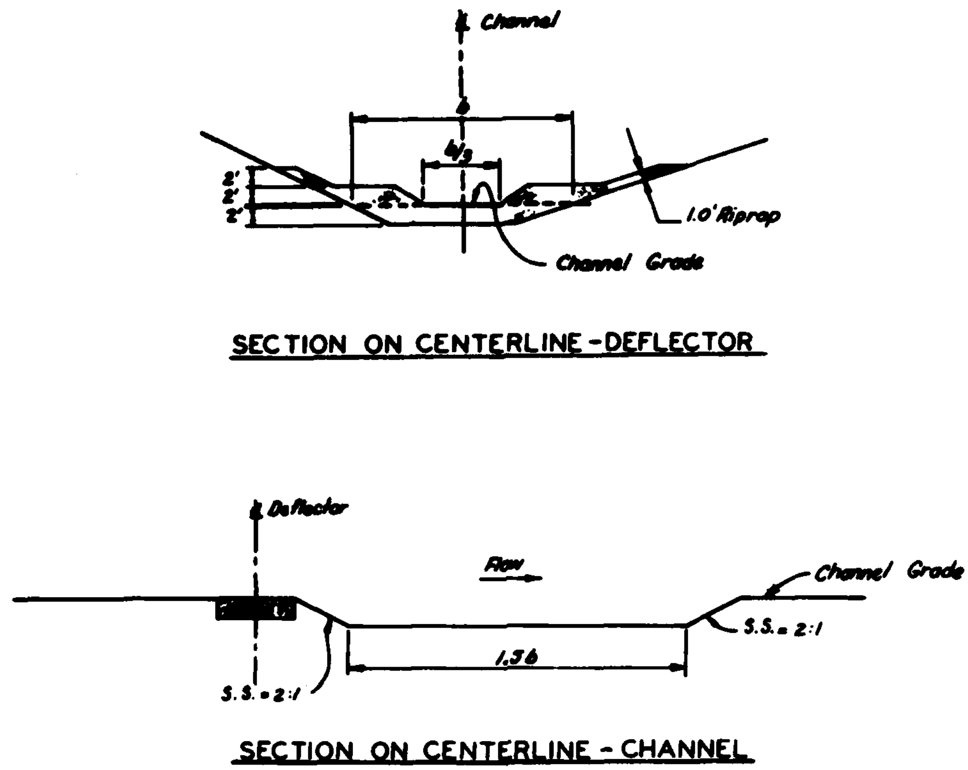


Figure A12. Typical design details for riprap sill installed in Prairie Creek

900 ft and have had negligible effects on channel capacity (U. S. Department of Agriculture Soil Conservation Service 1975).*

20. Biological effectiveness. The sills concentrated low flows in order to maintain the downstream scour holes at low flow; without these scour holes, low flow depths in the modified channel would have been insufficient for many aquatic species. The stone structures also provided stable substrate, acting as an artificial riffle. The deflectors have successfully maintained pools over a range of flow conditions without structural failure or channel stability problems.

---

* Supplemented by a personal communication from Mr. Elias Bloom and Mr. James D. McCall, U. S. Soil Conservation Service, Indianapolis, Indiana, to the author. Other channel projects are planned with up to 20 structures per mile of channel. The number of structures is determined based on preproject habitat inventories.

Electrofishing surveys conducted in similar channel projects have shown the pools downstream from the structures support a healthy aquatic community including several gamefish species (McCall and Knox 1978).*

Chippewa Creek and River Styx

21. Project description. Chippewa Creek, Ohio, was an SCS small watershed project, and River Styx a small headwater tributary within the Chippewa Creek watershed. Both streams were enlarged and straightened along almost their entire length (8 and 10 miles, respectively) for agricultural flood control. Both streams had been modified about 30 years previously as part of an agricultural drainage project. Mean daily flow in Chippewa Creek was about 25 cfs, channel widths ranged from 12 to 60 ft, channel slopes from 0.0002 to 0.0008, and channel design capacity from 280 to 1900 cfs. Bed material ranged from silt in the downstream reaches to sand and gravel in the upstream reaches. For River Styx mean daily flow was about 15 cfs, channel widths ranged from 8 to 34 ft, channel slopes from 0.0004 to 0.0014, and channel design capacity from 210 to 1000 cfs; the bed material was predominantly sand. Mean current velocity in both streams was 3 to 5 ft/sec at bankfull.**

22. Habitat structures. Rock deflectors and sills similar to the Prairie Creek structures were placed in Chippewa Creek. The deflectors extended approximately halfway across the channel. Crest elevations, which were 2 ft above channel grade, were just above the water surface at summer base flow and 4 to 6 ft under water during wet periods. Deflectors and two types of sills were used on River Styx: (a) a design similar to the Prairie Creek structure, and (b) a design similar to the artificial riffle structure in the Olentangy River. Structures for Chippewa Creek were built of stone with the following gradations:

---

* Supplemented by a personal communication from Mr. Elias Bloom and Mr. James D. McCall, U. S. Soil Conservation Service, Indianapolis, Ind., to the author. Other channel projects are planned with up to 20 structures per mile of channel. The number of structures is determined based on preproject habitat inventories.

** Personal communication from Mr. Joseph H. Harrington, U. S. Soil Conservation Service, Columbus, Ohio, to the author.

Weight of Individual Pieces, lb	Percent of Pieces this Weight, or Heavier
300	0
200	10-25
100	25-70
50	50-70
10	100

Structures for River Styx were built of material with a size gradation such that at least 85 percent of the material by weight was larger than a 9-inch square opening.*

23. Biological effectiveness. Carline and Klosiewski (1981) studied the effects of habitat structures on River Styx and Chippewa Creek for three years. Benthic populations in modified reaches of Chippewa Creek were not significantly greater at sampling stations with structures than stations with no structures. Chippewa Creek fish populations, on the other hand, responded positively to the habitat structures in terms of species diversity, density, and biomass. Sampling stations with structures consistently supported more fish species than stations without structures. Average fish density at stations with structures was 9.6 and 3.6 times the density at stations without structures in 1978 and 1980, respectively. Average fish biomass at stations with structures was 26.8 and 11.0 times the same value for stations without structures in 1978 and 1980, respectively.

24. Factors that contributed to differences in fish densities among stations in Chippewa Creek included substrate type, the presence of aquatic rooted plants, and variations in depth caused by the deflectors and sills. By constricting the flow, the habitat structures created a wide range of depths, substrate types, and current velocities (Figure A13). Deep pools supported the larger species of fish and game fish species (Carline and Klosiewski 1981).

25. Although the habitat structures in Chippewa Creek had a positive impact on fish diversity, density, and biomass, the relationship between game fish populations and structures was not statistically significant. Game fish species had very low densities and comprised a

* Personal communication, Harrington to the author.

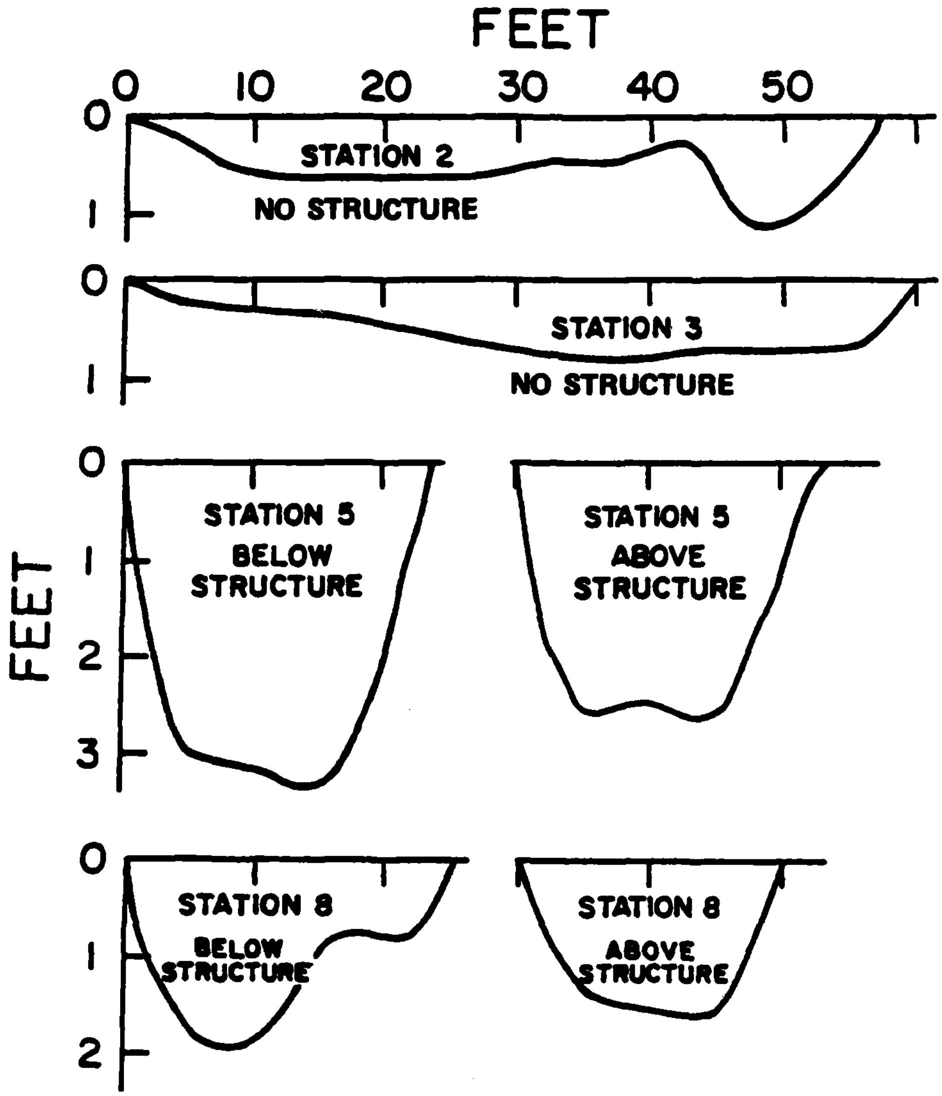


Figure A13. Effect of Chippewa Creek habitat structures on normal-flow channel cross section

relatively small fraction of the total catch in both Chippewa Creek and River Styx (3 to 4 percent in Chippewa Creek and 18 to 23 percent in River Styx). The low numbers of game fish may have been due to the absence of the quiet, protected backwaters required by centrarchids (sunfish) for successful spawning. Carline and Klosiewski (1981) proposed preservation of some unaltered reaches or creation of off-channel habitat ponds permanently connected to the stream to provide habitat for spawning and rearing.

26. Habitat structures were not as successful in the River Styx. Many of the rock sills did not create a typical chain of riffles and pools; this was because high flows and ice formation damaged some of the structures leaving shallow riffles composed of the structural remnants, but no pools. Some sampling stations did exhibit significant increases in fish species diversity, number of species, and abundance after installation of structures; but these increases may have been more indicative of improving water quality than of the influence of structures. The extensive use of riprap bank protection appeared to provide cover for small fish (Carline and Klosiewski 1981).

Summary and Conclusions

27. Project descriptions are presented in summary form in Table A1. In most cases, design procedues for existing habitat structures were unsophisticated. Conservation agencies usually suggested the use of habitat structures and the type and frequency of structures; construction agencies formulated structural designs based largely on professional judgement. Of the cases cited, there are no long-reach flood-control channel modifications designed to convey a low-frequency event. The Fisher River project was designed to handle the 50-year event, but it consisted of a series of relatively short channel changes built to cut off bends and make room in the valley floor for construction of a railroad embankment. Habitat structures were not effective in restoring the sport fishery in the Fisher River, and several of the structures have failed. Habitat structures in modified channels have experienced greatest success in streams with coarse bed material and little or no channel enlargement.

28. It can be concluded from the studies reviewed above that habitat structures are not effective in restoring game fish populations when constraints other than physical habitat characteristics limit populations. Factors which can limit fish populations include water quality degradation, lack of depths and velocities required for spawning and rearing, and absence of riparian vegetation. Structures are also

Table A1

Summary of Project Descriptions for Modified Channels with Habitat Structures

Stream	Mean Daily Flow, cfs	Channel Capacity cfs	Channel Slope	Bed Material	Total Length of Modified Channel mile	Bottom Width ft	Constructing Agency
Fisher River, Mont.	520	7800	0.007	Sandy silty gravel with cobbles and boulders	4.3	100-125	CE
Rapid Creek, S. D.	30	500	0.005	Gravel, rubble	0.6	30	CE
Weber River, Utah	255	5400	0.025-0.047	Gravel, rubble	1.6	70	Utah Dept of Highways
Olentangy River, Ohio	460	8-10,000	0.0007	Clay, silt, sand, gravel	0.8	120	Ohio DOT
Crow Creek, Ala.	200-300	2000	0.001	Gravel, sand, some clay and silt	9.2	30-60	SCS
Prairie Creek, Ind.	25	160-640	0.001	Silty clay, sandy clay, gravelly sandy clay	4.0	8-28	SCS
Chippewa Creek, Ohio	25	280-1900	0.0002-0.0008	Silt, sand, gravel	10.4	12-60	SCS
River Styx, Ohio	15	210-1000	0.0004-0.0014	Sand	7.9	8-34	SCS

ineffective when they decrease rather than increase habitat diversity. Biological recovery of modified reaches equipped with habitat structure is greatly enhanced by the presence of nearby unaltered reaches.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Shields, F. Douglas
Environmental features for flood-control channels / by F. Douglas Shields, Jr. (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station, 1982.
107, 26 p. : ill. ; 27 cm. -- (Technical report ; E-82-7)
Cover title.
"July 1982."
Final report.
"Prepared for Office, Chief of Engineers under EWQOS Task VIB."
At head of title: Environmental & Water Quality Operational Studies.
Bibliography: p. 99-107.

1. Channels (Hydraulic engineering). 2. Environmental impact analysis. 3. Flood control. I. United States.

Shields, F. Douglas
Environmental features for flood-control channels : ... 1982.
(Card 2)

Army. Corps of Engineers. Office of the Chief of Engineers. II. Environmental & Water Quality Operational Studies. III. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. III. Title IV. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; E-82-7.
TA7.W34 no.E-82-7